HUDSON LAKE ENHANCEMENT FEASIBILITY STUDY

Prepared for
Hudson Lake Conservation Club
Hudson Lake, Indiana

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Chicago, Illinois

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HUDSON LAKE ENHANCEMENT PROJECT
Feasibility Study

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EXECUTIVE SUMMARY

This lake enhancement feasibility study assessed environmental conditions in Hudson Lake and its watershed, identified sources of water quality and recreational problems in the lake, and evaluated alternatives for remediating these problems. Nutrient levels were measured to be moderate; light penetration and transparency were found to be relatively good, compared to other rural lakes in northeastern Indiana.

Sediment loadings to Hudson Lake were estimated using the Universal Soil Loss Equation. Erosion in the watershed is moderate. Sedimentation rates in Hudson Lake were computed to be between 0.03 and 0.13 inches per year, the higher rates occuring in Little Hudson Lake. We estimated that Saugany Lake traps about 1,450 tons of sediment per year, keeping it from entering Hudson Lake. Little Hudson Lake is also quite valuable in protecting the main body of Hudson Lake from nonpoint source sediment, as it was found to trap about 2,276 tons annually, or, about 96% of the sediment entering the lake from the west.

Sanitary quality of Hudson Lake is poor for a lake routinely used for primary contact recreation (swimming). Bacteriological data acquired by the Department of Environmental Management indicates poor performance or improper installation of lakeshore septic systems. We recommend that further investigations, and appropriate remediation, be performed on septic contamination of the lake.

Aquatic macrophytes are a nuisance in some locations around the lake. We recommend that a detailed plant management plan be prepared to prioritize areas for public uses, and to specify the locations and degrees of macrophyte control to support these uses. Harvesting of aquatic plants would cost upwards of $35,000 annually, while an herbicide program would cost about $13,500 per year. Not withstanding the obvious cost disadvantage, harvesting is recommended over herbicides due to harvesting's innate lake restorative value. Harvesting removes nutrients from the system, whereas herbicide applications only change the organic form of the nutrients (planktonic rather than macrophytic).

Best management practices for Hudson Lake should focus on the residential areas immediately around the lake as well as the upland agricultural areas. The HLCC can consult with the "T by 2000" office for technical assistance for non-agricultural and agricultural watershed management planning. Wetlands in the watershed should be protected and where possible restored for flood control, wildlife habitat enhancement, and water quality improvement.

PHYSICAL DESCRIPTION OF THE STUDY AREA

Introduction

In 1988, the Hudson Lake Conservation Club (HLCC) received a committment from the Indiana Department of Natural Resources (DNR) for technical and financial lake enhancement assistance. The HLCC was given a grant under the DNR's "T by 2000" Lake Enhancement Program. The grant funds were used to procure the services of a consulting engineer to perform a lake enhancement feasibility study. Harza Engineering Company was contracted in 1990 to review and complete the feasibility study begun by another firm, that had since declared bankruptcy.

Harza's specific scope of services for this study included five tasks: Data Collection, Field Investigations, Data Analyses, Evaluation of Alternatives, and Report Preparation. Data Collection included assembling a database on the lake, its watershed, and other natural resources by contacting appropriate State and Federal agencies. Field Investigations included performing certain water quality testing, aquatic macrophyte studies, and checking existing watershed, soils, and land use maps. Data Analysis included computing a new Lake Eutrophication Index, estimating a phosphorus budget, and estimating watershed sediment yield and lake sedimentation. Evaluation of Lake Enhancement Alternatives included identifying measures that the Conservation Club can implement for improvements in Hudson Lake and evaluating these alternatives based upon technical, environmental and cost criteria. A report detailing this feasibility study was to be prepared and a presentation made to HLCC.

General Description

Hudson Lake is located in northeast LaPorte County, Indiana. The lake is in Hudson Township. Figure 1 is a location map.

Figure 2 is a map of Hudson Lake, showing bottom contours and shoreline lands. DNR lake maps indicate the lake's volume is 5,060 acre-feet; average depth is 11.7 feet. Hudson Lake has a mean hydraulic retention time of about 400 days.

Hudson Lake is a kettle lake, formed during the retreat of continental glacial ice sheets in the late Pleistocene period. The lake is referred to as two bodies of water, separated by a 3.4-acre residential island: a larger (eastern) lake with a maximum depth of 42 feet (13 m); and Little Hudson Lake west of the island, smaller and shallower (maximum depth near 10 feet) than Hudson Lake. This separation of the lake into two volumes is significant in the eutrophication, or aging, of the lake and will be discussed in detail in later sections of this report. Little Hudson Lake has the lake's only major tributary, and consequently receives much of the storm runoff before it passes east of the island to Hudson Lake.

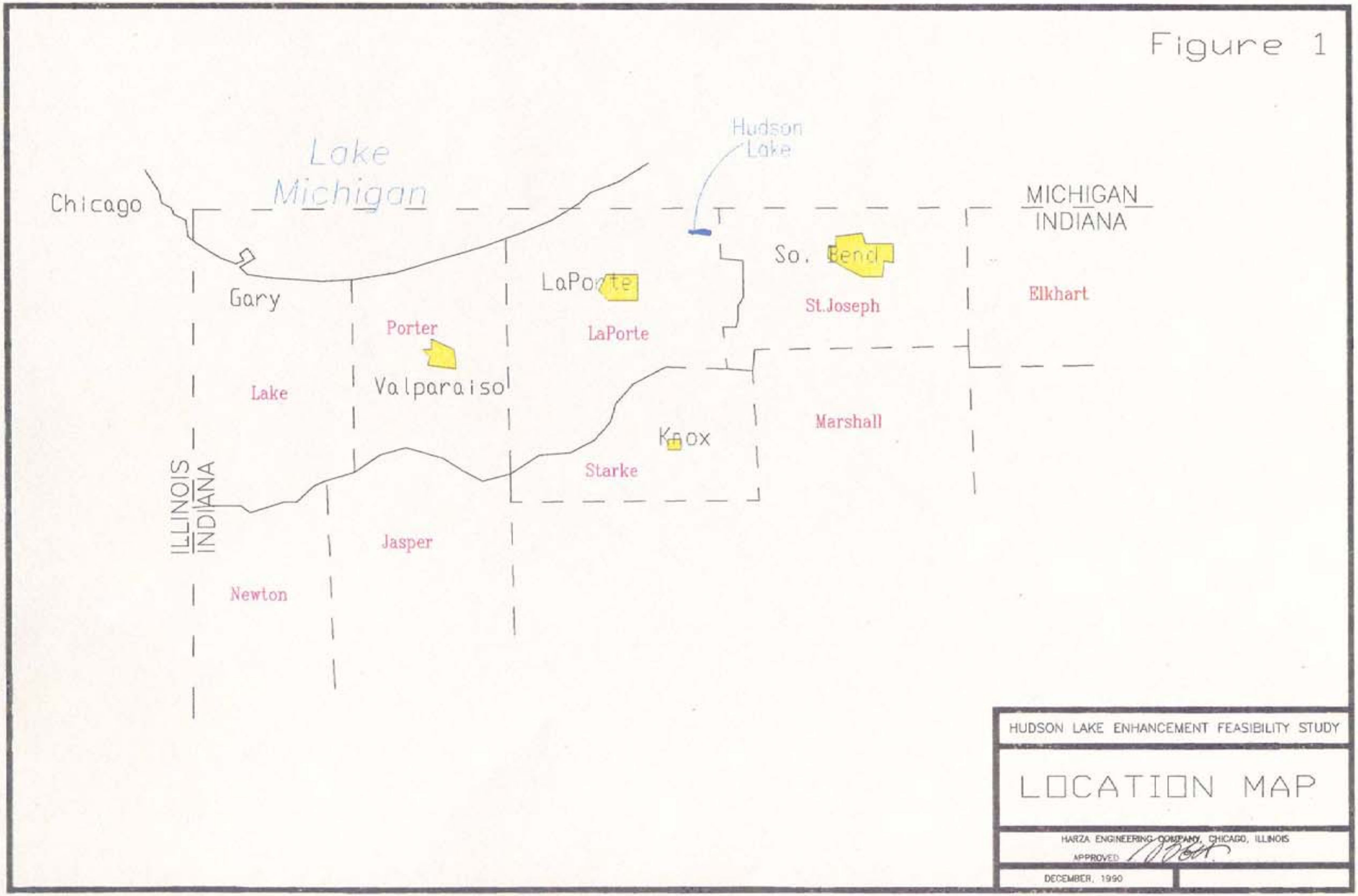
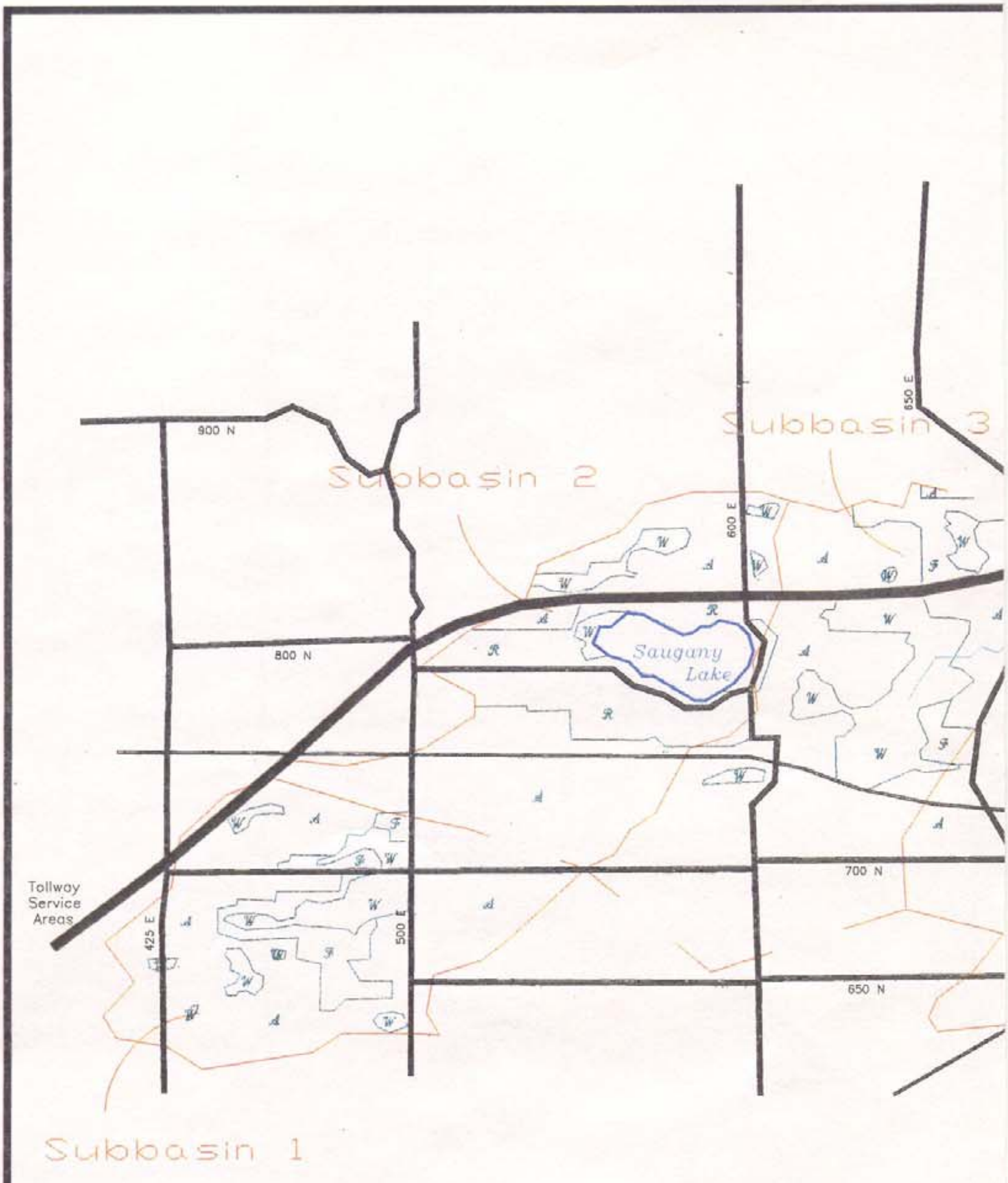


Figure 1
Hudson Lake
Lake Michigan
Chicago
MICHIGAN
INDIANA
So. Bend
LaPorte
Gary
St.Joseph
Elkhart
Porter
LaPorte
Lake
Valparaiso
Marshall
Knox
Starke
ILLINOIS
INDIANA
Jasper
Newton
HUDSON LAKE ENHANCEMENT FEASIBILITY STUDY
LOCATION MAP
HARZA ENGINEERING COMPANY, CHICAGO, ILLINOIS
APPROVED
DECEMBER, 1990

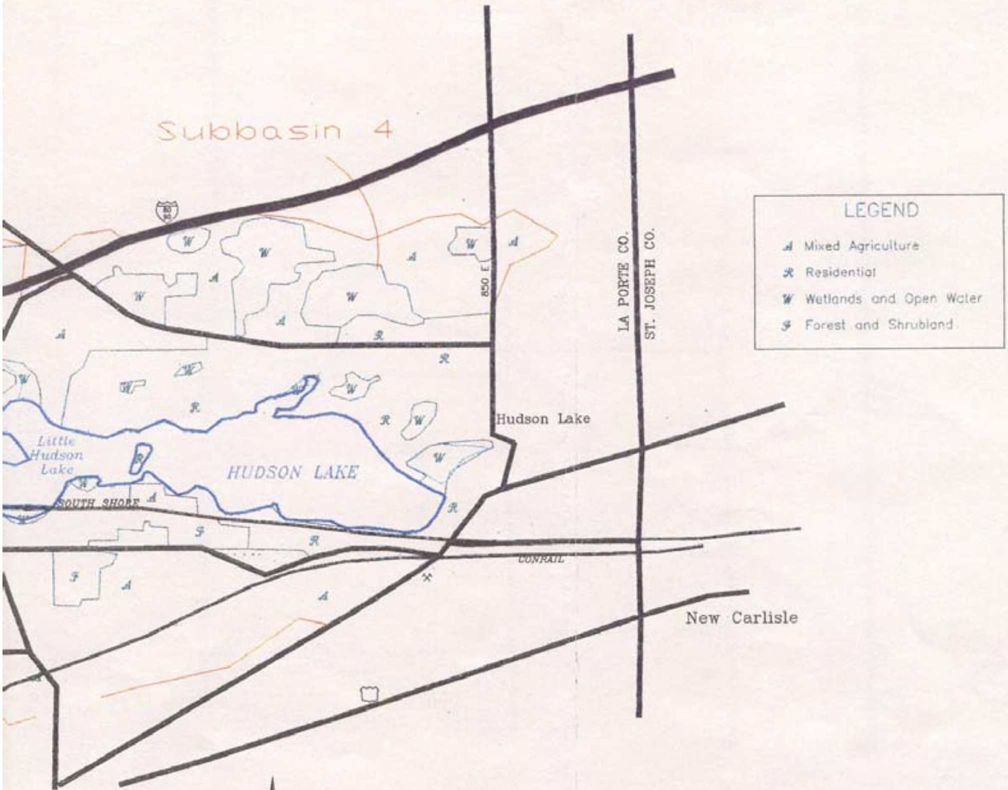
Figure 2

HUDSON LAKE ENHANCEMENT FEASIBILITY STUDY	
LAKE BOTTOM MAP	
HARZA ENGINEERING COMPANY, CHICAGO, ILLINOIS APPROVED	
DECEMBER, 1990	



Subbasin 2
Subbasin 3
Subbasin 1
900 N
800 N
700 N
650 N
425 E
500 E
600 E
650 E
Saugany Lake
Tollway Service Areas
1
1/2
0
1 MILE
SCALE

Figure 3



HUDSON LAKE ENHANCEMENT FEASIBILITY STUDY

LAND USE/
LAND COVER MAP

HARZA ENGINEERING COMPANY, CHICAGO, ILLINOIS

APPROVED ....

DECEMBER, 1990

5,440 — 4650

Hudson Lake's drainage area is about eight and one-half square miles, of which 790 acres is a closed wetland that does not contribute water or solids to Hudson Lake. Saugany Lake, approximately 1.7 miles upstream of Hudson Lake, is included in Hudson Lake's drainage area. Hudson Lake is a natural lake, with no perennial tributaries. During storm events, most of the watershed drains into the northwest corner of Little Hudson Lake. Other avenues of water entry are overland flow from the immediate surrounding area and direct precipitation.

Groundwater is also a major component of the lake's water budget. Hudson Lake is partially dependant upon groundwater for maintenance of water levels. The lake level is also controlled by a 24-inch concrete pipe and gate on the east shore. The outlet eventually leads to the Kankakee River.

Hudson Lake is heavily developed by shoreline residents. Little Hudson Lake is much less developed but some homes do exist in that portion of the lake. Hudson Lake is used for public recreation. There is a small parking area and public access along the beach by Lakeshore Ave. Boating, angling (including ice fishing), and swimming are three of the most common uses.

For several decades, recreation on Hudson Lake has been adversely affected by the preponderance of aquatic macrophytes. Boating, in particular, has been affected by the weeds. The Hudson Lake Conservation Club has not implemented any organized weed control program.

Watershed Characteristics

Figure 3 is a map of the Hudson Lake vicinity, showing the watershed boundary and land use/land cover in the watershed. The watershed was divided into four subbasins for study. Subbasin 1, the southwest corner of the basin, is non-contributing. Subbasin 2 includes Saugany Lake and the residential areas around it. Subbasin 3 is the area between Saugany and Hudson Lakes, and includes a large fen (an alkaline wetland, somewhat rare in northern Indiana). Subbasin 4 is the largest of the subbasins, and includes Hudson Lake and the immediate drainage area.

Information used to generate Figure 3 included aerial photographs obtained from the County taken in spring of 1980, topographic maps, and the National Wetland Inventory map. Land use/land cover was studied as four simple categories: wetlands and deep water habitats, forest, residential or urbanized land, and mixed agriculture which includes pastures, row crops, and orchards.

The watershed area is 5,455 acres, but only 4,665 acres, or 65% are contributing to the water and nutrient budget of Hudson Lake. The cover/use of land in the watershed is primarily mixed agriculture. The 1980 aerial photographs indicate that between 87 and 90% of the agricultural land is under tillage for row crop production.

Table 1

HUDSON LAKE WATERSHED LAND USE

Subbasin	Wetlands	Forest	Urban	Mixed Farming	Total
1	87	92	0	620	799
2	120	0	242	503	865
3	179	71	13	827	1,091
4	545	205	578	1,373	2,701
Total	**931**	**368**	**833**	**3,323**	**5,455**

The LaPorte County Soil Survey indicates soils in the watershed to be of two basic map units: Tracy Chelsea soils on glacial outwash plains and eolian uplands, and Riddles soils which are well drained, loamy glacial till (SCS 1982). The most common soil type is Tracy sandy loam, generally used for cultivation. Conservation practices are recommended by the SCS for this map unit to control erosion and surface runoff.

AQUATIC RESOURCES

Methods

Water, sediment, and plankton sampling was performed both for the 1988 study and for the study of the summer of 1990. Water and sediment samples were collected in the vicinity of the deepest locations in Hudson and Little Hudson Lakes.

Harza biologists collected plankton samples using an 80-micrometer mesh, self-closing Birge-type plankton net. The plankton were preserved in the field with Lugol's solution. The algal tow was done at the same location sampled for water quality testing. One plankton tow included the top five feet of the water column; the second tow was from the twenty-foot depth to the fifteen-foot depth. Plankton were counted using a Sedgewick-Rafter cell and identified based upon a key published in APHA et al. (1985).

Water samples were collected on sunny days, just after the noon hour. Water samples were collected using a Kemmerer bottle. Sediment was collected using a brass Ekman dredge. Water was sampled and tested according to Standard Methods (APHA et al. 1985). Initially, we checked for the existence of a thermocline using a Yellow Springs Instruments Model 57 dissolved oxygen meter equipped with a temperature sensor. Upon determining the location of the thermocline, the Kemmerer bottle was used to collect samples representative of the epilimnion and the hypolimnion.

Dissolved oxygen (DO) and temperature were measured using the YSI model 57 DO meter; conductivity with a YSI model 33 Salinity-Conductivity-Temperature meter. Light transmission was determined using a LiCor model LI-185B photometer with an underwater photocell. Total alkalinity was measured by titration to a colorimetric endpoint. Secchi disk visibility was measured in the field using a standard eight-inch black and white disk. Other parameters were measured in the laboratory using samples collected and preserved in the field according to Standard Methods. Samples were kept on ice from the moment of collection until they reached the laboratory.

Quality assurance/quality control measures included collection of a duplicate epilimnetic water sample for nutrient analyses, calibration of all meters in the field prior to their use according to manufacturer's instructions, and maintenance of Chain-of-Custody procedures. For the samples collected in 1988, EIS Environmental Laboratory (South Bend) performed the testing. In 1990, the contract laboratory was National Environmental Testing Midwest, of Streamwood, Illinois.

Fisheries

The Department of Natural Resources (DNR) Division of Fisheries last surveyed the fish population of Hudson Lake in summer of 1990 (DNR unpublished data). Fifteen species of fish were collected in the lake. In order of decreasing abundance the DNR found the following fishes in Hudson Lake: bluegill (*Lepomis macrochirus*), yellow perch (*Perca flavescens*), and redear sunfish (*Lepomis microlophus*). These three species composed 65% of the fishes captured, about 37% by weight. These fishes are commonly dominant in lakes with an abundance of macrophytic vegetation. Twelve bowfin (*Amia clava*) composed 15% by weight of the catch; six northern pike (*Esox lucius*) were 11% of the catch. Other fish surveys were performed by the DNR in 1981, 1978, and 1972. In general, Hudson Lake supports fishable populations of sunfish, northern pike, largemouth bass (*Micropterus salmoides*), and bullhead (*Ictalurus* spp.).

Macrophytes and Phytoplankton

The DNR fish management reports also listed aquatic plants found in the lake during their surveys. The reports stated that aquatic weeds were very abundant, covered about 60% of the lake, and recommended a control program be implemented for submersed plants.

During Harza's water and sediment sampling visit, aquatic plant communities were inspected by snorkeling, and specimens were collected for verification in the laboratory. Collected specimens were dried, mounted, and replicates sent to the Indiana State Museum for independent identification. (To date, no response has been received from the museum.) Three areas of the lake had sufficient abundances of macrophytes to warrant surface and underwater inspections, and, potentially, control programs: the east shore of the lake, the general vicinity of the island, and Little Hudson Lake. A fourth area, a large monotypic expanse of bulrushes (*Scirpus* spp.) on the north shore, was also inspected. Table 2 is a composite list of aquatic macrophytes in Hudson Lake identified by Harza or the DNR.

The HLCC does not have an organized macrophyte control program, although they sponsored a pilot-scale harvesting project in 1989. It was quite clear from the snorkeling surveys that some residents have controlled aqutic plants immediately in front of their homes. This was most apparent off the east shore of the island.

Submersed vegetation is impairing public use of the lake and should be managed. Emergents are less of a problem, but may deserve some control, particularly on the east shore of the island. Little Hudson has few shoreline residents and its use is primarily for fishing, with some waterfowl hunting occurring there. Emergent vegetation generally offers excellent cover, nesting and rearing habitat for waterfowl and aquatic mammals and control efforts in this area should be limited to maintaining boat access lanes.

Table 2

AQUATIC MACROPHYTES IN HUDSON LAKE

Common Name	Scientific Name	East Shore	Island	Little Hudson Lake
Emergents				
White waterlily	*Nymphaea tuberosa*	X	X	X
Spatterdock	*Nuphar luteum*	X	X	X
Cattail	*Typha*	X	X	X
Bulrushes	*Scirpus*		X	X
Waterwillow	*Diathera americana*		X	X
Arrowhead	*Sagittaria*	X	X	X
Submersed Species				
Coontail	*Ceratophyllum demersum*	X	X	X
Curlyleaf Pondweed	*Potamogeton crispus*	X	X	X
Wild Celery	*Vallisneria americana*	X	X	X
Watermilfoil	*Myriophyllum*	X	X	X
Sago Pondweed	*Potamogeton pectinatus*	X		
Longleaf Pondweed	*Potamogeton nodosus*	X	X	X
Naiads	*Najas*	X	X	X
Elodea	*Elodea canadensis*			
Giant Bladderwort	*Utricularia foliosa*		X	
Floating Pondweed	*Potamogeton natans*		X	
Threadleaf Pondweed	*Potamogeton filiformis*		X	
Illinois Pondweed	*Potamogeton illinoensis*			
Algae				
Chara	*Chara*	X	X	X

Table 3 lists plankton found in Hudson Lake on September 5, 1990. Three genera dominated the plankton community. Bluegreen algae (Division Cyanophtya) were particularly common. *Gomphosphaeria*, a bluegreen species was the most numerous alga, and constituted about 80% of the units counted. *Anabaena spiroides*, also a bluegreen alga, occurs in beadlike colonies; if the individual cells had been counted rather than the colonies, that species would have been the most abundant.

Table 3

PLANKTON CONCENTRATIONS (units/mL)
IN HUDSON LAKE ON SEPTEMBER 5, 1990

	0-5 ft Concentration	15-20 ft Concentration
PYRRHOPHYTA		
Ceratium hirundinella	6	3
CHRYSOPHYTA		
Fragilaria	7	6
Synura unella	1	6
Dinobryon	6	
CHLOROPHYTA		
Chlorococcum		5
Actinastrum		2
Spirogyra	1	2
Ulothrix		2
Micractinium pusillum		5
CYANOPHYTA		
Hydrurus	5	
Anabaena spiroides	39	8
Gomphosphaeria	356	335
Microcystis	7	3
Anastysis	4	19
ZOOPLANKTON		
Daphnia retrocurva	3	3
Senecella calanoides		2
Trichocerca	1	
Leptodiatomus siciloides	3	
Eucyclops speratus		2
Eubosmina coregoni	1	
	440	401

Water and Sediment Quality

Results of the August 11, 1988 and September 5, 1990 water and sediment quality testing are given in Table 4 and Figure 4. Different laboratories were used for analytic services in 1988 than in 1990. The 1988 laboratory, in general, had higher detection limits than the 1990 contract laboratory, and, are therefore, the data are somewhat less informative.

As is clearly shown in Figure 4, the lake was thermally stratified during both sampling occasions. The depth range of the thermocline (the depth of rapid water temperature change) was similar in August 1988 and September 1990, being from about 14 feet to 26 feet in both years. However, the epilimnetic-hypolimnetic temperature differential was much stronger in 1988, with a $\Delta T = 16^{\circ}$ C in 1988, compared with a $\Delta T = 7^{\circ}$ C in 1990. The stronger stratification in 1988 was due to different climatic and hydraulic factors; 1988 was a record hot and dry summer. Apparently, the lake statified later in 1990 than in 1988, after the lake bottom waters had warmed somewhat.

The surface water was well oxygenated during both sampling occasions, with 7.5 to 8.0 mg/L dissolved oxygen (DO). During both summers, the lake had less that 0.5 mg/L DO in the hypolimnion.

Light penetrated the water column quite well on September 5, 1990, the only time light attenuation was measured. Figure 5 shows light attenuation with depth. The total extinction coefficient varied between 0.64 and 1.0 m^{-1}; all measurements averaged 0.77 m^{-1}. Photosynthesis generally occurs to the depth to which one percent of incident radiation penetrates; on Sept 5, 1990, this depth was about 20 ft. Dissolved oxygen, a by-product of photosynthesis dropped to nearly zero below this depth.

Transparency, as measured by secchi disk visibility, was about 11 feet in September, 1990. In August, 1988, transparency was about eight feet, lower than the 1990 value due to, among other things, decreased flushing of the lake in that dry year. These measurements of light attenuation and transparency are generally good for a lake in northern Indiana.

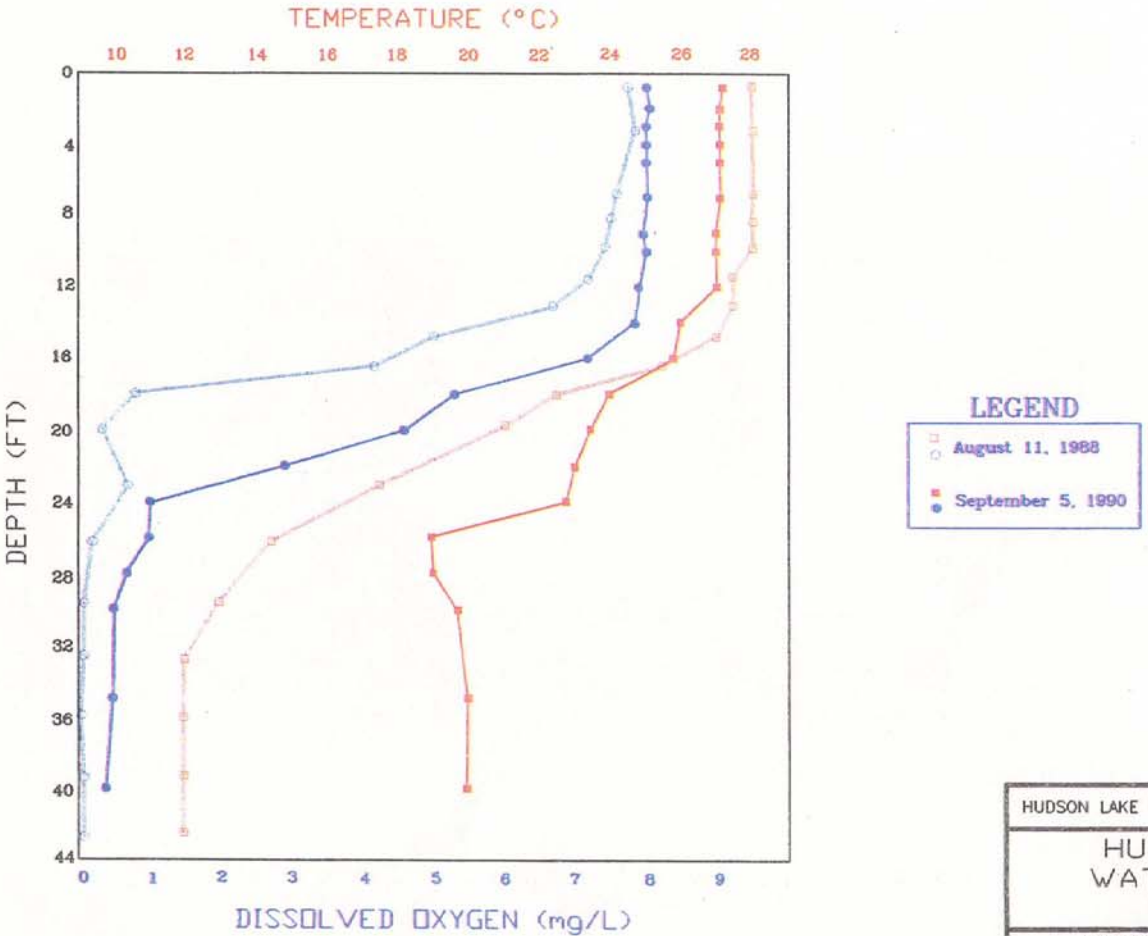
Relative to many area lakes, nutrient levels in Hudson Lake are low. Water column average total phosphorus levels were about 0.18 mg/L in 1988, and about 0.06 mg/L in 1990. The US EPA National Eutrophication Survey (USEPA 1974) considered total phosphorus concentrations above 0.02 mg/L to be eutrophic lakes. According to the US EPA, mesotrophic (moderately productive) lakes have 0.01 to 0.02 mg P/L, and oligotrophic lakes (low productivity) have total phosphorus concentrations less than 0.01 mg/L. Hence, Hudson Lake has phosphorus concentrations in the range the US EPA would consider representative of eutrophic lakes.

Table 4
WATER AND SEDIMENT QUALITY IN HUDSON LAKE

Site	Sample Type or Depth	Date (d/m/y)	Time	Ammonia Nitrogen (mg N/L)	Kjeldahl Nitrogen (mg N/L)	Nitrate Nitrogen (mg N/L)	Nitrite Nitrogen (mg N/L)	Total Nitrogen (mg N/L)	Soluble Phosphorus (mg P/L)	Total Phosphorus (mg P/L)	N to P Ratio
Hudson Lake	5 ft	11/8/88		<0.05	2.4	<0.04	<0.04	2.4	<0.16	0.22	24
Hudson Lake	16 ft	11/8/88		<0.05	3.6	<0.04	<0.04	3.6	<0.16	0.04	199
Hudson Lake	29 ft	11/8/88		<0.05	3.2	<0.04	<0.04	3.2	<0.16	0.04	177
Hudson Lake	Composite	11/8/88		<0.05	1.0	<0.04	<0.04	1	<0.16	0.18	12
Little Hudson Lake	2 ft	11/8/88		<0.05	1.6	<0.04	<0.04	1.6	<0.16	0.25	14
Little Hudson Lake	Sediment	24/8/88								3.1 mg/kg	
Hudson Lake	3 ft	6/9/90	13:30	0.26	0.52	0.13	<0.01	0.65	<0.01	0.11	13
Hudson Lake	40 ft	6/9/90	13:30	0.23	0.91	<0.01	<0.01	0.91	<0.01	0.02	101
Hudson Lake	3 ft	6/9/90	13:30	0.22	0.66	0.28	<0.01	0.94	<0.01	<0.01	>257
Inlet Stream	Storm event	19/9/90	13:00	2.40	5.04	0.59	<0.01	5.63	0.20	0.48	26
Hudson Lake	Sediment	6/9/90	13:00	24.5 mg/kg	992 mg/kg					29.4 mg/kg	

Site	Sample Type or Depth	Date (d/m/y)	Biochemical Oxygen Demand (mg/L)	Total Suspended Solids (mg/L)	pH	Total Alkalinity (mg CaCO3/L)	Conductivity (umhos/cm)	Secchi Disk (ft)	Fecal Coliforms (/100 mL)	Fecal Streptococcus (/100 mL)	FC to FS Ratio
Hudson Lake	5 ft	11/8/88	<2	5		120	340	8.2	6		
Hudson Lake	16 ft	11/8/88	<2	4					400		
Hudson Lake	29 ft	11/8/88	2	9					420		
Hudson Lake	Composite	11/8/88	<2	10					1,180		
Little Hudson Lake	2 ft	11/8/88	<2	4					2		
Little Hudson Lake	Sediment	24/8/88									
Hudson Lake	3 ft	6/9/90		2	7.6	120	280	10.9	1	0	
Hudson Lake	40 ft	6/9/90		8	7.3	120	270		0	0	
Hudson Lake	3 ft	6/9/90									
Inlet Stream	Storm event	19/9/90	6	132					8,900	183	49
Hudson Lake	Sediment	6/9/90									

Figure 4



HUDSON LAKE ENHANCEMENT FEASIBILITY STUDY

HUDSON LAKE
WATER COLUMN
PROFILE

HARZA ENGINEERING COMPANY, CHICAGO, ILLINOIS

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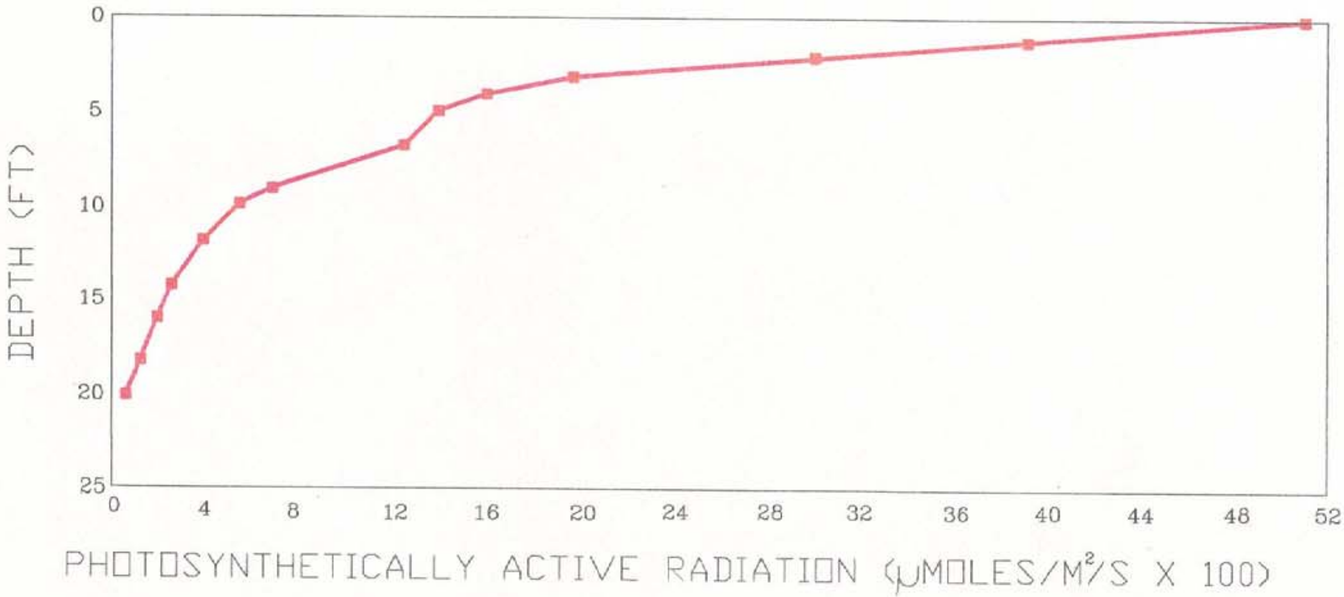
DECEMBER, 1990

Figure 5



HUDSON LAKE ENHANCEMENT FEASIBILITY STUDY

LIGHT ATTENUATION
ON SEPT 5, 1990

HARZA ENGINEERING COMPANY, CHICAGO, ILLINOIS

APPROVED

DECEMBER, 1990

Water column average total nitrogen levels ranged from less than one mg/L to three mg/L. The incoming water of the September 19, 1990 storm event had levels of both inorganic and organic nitrogen that were an order of magnitude greater than the lake water column.

The nitrogen to phosphorus ratio (N:P), an indicator of which of these two nutrients limits productivity, ranged between 12 and about 200. This range of values places Hudson Lake in the phosphorus-limited category (Wetzel 1983). The productivity of most freshwaters in North America is phosphorus limited.

Fecal coliform and streptococcus bacteria are indicators of sewage contamination. In 1988, fecal coliforms were rather high in Hudson Lake, beyond the levels generally considered safe for contact recreation. The 1990 data indicate very few of these bacteria were in Hudson Lake. The September 19, 1990 storm event however carried very high concentrations of coliform bacteria into the lake. The fecal coliform to fecal streptococcus ratio (FC:FS) is a general indicator of the source of pollution. FC:FS above 4.1 is considered to be indicative of pollution derived from human excrement, whereas FC:FS less than 0.7 suggests pollution due to non-human sources such as livestock, wildlife or pets (APHA et al. 1985). The FC:FS in the storm sample was 49, likely indicating human sources, and, suggests further sampling is warranted.

In addition to nitrogen and coliform bacteria, the storm sample also contained rather high biochemical oxygen demand and suspended sediments. Immediately upstream of the site of the storm runoff sampling, cattle are being pastured and have access to the stream. These cattle could be the source of much of these loadings, despite the FC:FS suggestion of human sources.

For comparison to the water quality data, the State's water quality standards, which are applicable to Hudson Lake, are given in Table 6. Hudson Lake, as all lakes and reservoirs in the state, is designated for recreational use (including whole-body contact recreation) and support of warm water aquatic life, and must meet the water quality standards to support these uses. Hudson Lake was within the state's standards during the days sampled.

Sediment quality data from this study are given in Tables 4 and 5. Sediments were collected in Little Hudson Lake in 1988, and from Hudson Lake in 1990. Based upon other studies by Harza on other northern Indiana lakes, sediment nutrient concentrations are rather low in Hudson Lake. No Priority Pollutants were detected by the laboratory in the 1988 Little Hudson Lake sediment sample.

Table 5
HUDSON LAKE SEDIMENT QUALITY DATA

Parameter	Concentration
Ammonia nitrogen	24 ug/g
Kjeldahl nitrogen	992 ug/g
Total phosphorus	29 ug/g
Total organic carbon	163 mg/g
Particle Size Distribution	
#60 sieve (0.25 mm)	12%
#80 sieve (0.2 mm)	13%
#100 sieve (0.15 mm)	14%
#200 sieve (0.075 mm)	15%
#230 sieve (0.06 mm)	14%
Pan (<0.6 mm)	32%

Table 6

WATER QUALITY STANDARDS APPLICABLE TO HUDSON LAKE

Parameter	Standard
Dissolved Oxygen	Daily Average of 5.0 mg/L Minimum of 4.0 mg/L
pH	6.0 - 9.0
Fecal Coliform Bacteria	Less than 400/100 mL or less than 200/100 mL per 5 samples in 4-week period

Source: Indiana Administrative Code, Title 330, Article 1. Water Quality Standards.

Other Resources

The DNR Division of Nature Preserves was contacted during this study and requested to review their files for information on the occurrence of threatened or endangered species or their critical habitat, and, the occurrence of natural areas in the Hudson Lake vicinity. After checking the Natural Heritage Program's database, they indicated that the large wetland lying west of Emery Road between Hudson Lake and Saugany Lake is a marly fen and should not be disturbed. They also informed us that Little Hudson Lake harbors two aquatic plant species of concern: the state-listed endangered lesser bladderwort (*Utricularia minor*) and the special concern species *Juncus balticus*, a rush. The Division requested that aquatic vegetation control measures avoid affecting these plants.

PROBLEM IDENTIFICATION

Lake Eutrophication Index

A Eutrophication Index (EI) based upon the Indiana Department of Environmental Management's system (IDEM, 1986) was updated for Hudson Lake as part of this study. An EI is a numerical rating of a lake's trophic or productivity status; the higher the index, the greater the lake's productivity.

Table 7 details our computation of the EI, based upon the IDEM system. The 1990 water quality data were used for this EI computation. In the mid-1970s, the IDEM computed a LEI to be 23 eutrophy points. The updated EI is 16, which represents improved water quality. Lakes with less than 25 eutrophy points are considered by IDEM to be Class One lakes, that is, the highest quality, least eutrophic lakes in Indiana. These numbers should be interpreted with some caution, however, as the two calculations represent, in part, instantaneous conditions on the day the sampling was done. Thus, a single EI can be biased by a significant amount due to normal fluctuations in one or more parameters.

Also in the mid-1970s, the IDEM computed an EI for Saugany Lake of 1, making it the least eutrophic lake in the state. Saugany Lake is in Hudson Lake's watershed and prevents upstream sediments and associated nutrients from continuing downstream into Hudson Lake.

Nonpoint Source Pollution Assessment

The 1989 IDEM Nonpoint Source Assessment Report indicated that an evaluation of Hudson Lake had determined that the lake's designated use for support of aquatic life was impaired. IDEM stated that the probable source of this impairment was non-irrigated crop production and landfills, and, that the probable cause was nutrients and siltation.

Lake Phosphorus Model. Lake phosphorus (P) loadings to Hudson Lake and mean annual water column phosphorus concentrations were estimated using an empirical model developed by Reckhow (Reckhow and Chapra, 1983; Reckhow and Simpson, 1980). Reckhow's model was chosen for use because it quantifies uncertainty and was developed using data from many lakes in the Midwest. Computation of uncertainty is important here because of the limited field data available.

Table 7

ISBH LAKE EUTROPHICATION INDEX FOR HUDSON LAKE

	Parameter	Measured Value (units)		Eutrophy Points
I.	Total Phosphorus	0.065	ppm	3
II.	Dissolved Ortho Phosphorus	<0.01	ppm	0
III.	Organic Nitrogen	0.48	ppm	0
IV.	Nitrate Nitrogen	0.068	ppm	0
V.	Ammonia Nitrogen	0.24	ppm	0
VI.	Dissolved Oxygen Saturation at five feet from surface	106	%	0
VII.	Dissolved Oxygen (% measured water column with >0.1 ppm DO)	100	%	0
VIII.	Light Penetration (Secchi Disk)	10.9	feet	0
IX.	Light Transmission (% transmittance at 3 ft)	38	%	3
X.	Total Plankton (single tow)			
	Vertical tow, 5 ft to surface	440	cells/mL	0
	Blue-green dominance?	Yes		5
	Vertical tow, from thermocline	401	cells/mL	0
	Blue-green dominance?	Yes		5
			EI=	16

Reckhow's model is based on data from 47 northern temperate lakes included in the US EPA's National Eutrophication Survey. The model expresses phosphorus concentration (P, in mg/L) as a function of phosphorus loading (L, in g/m^2-yr), areal water loading (q_s, in m/yr), and apparent phosphorus settling velocity (v_s, in m/yr) in the form of equation 1:

$$P = \frac{L}{v_s + q_s} \qquad \text{(Eq. 1)}$$

By least squares regression of the 47 lakes data, Reckhow fitted apparent phosphorus settling velocity as a weak function of areal water loading:

$$P = \frac{L}{11.6 + 1.2q_s} \qquad \text{(Eq. 2)}$$

Using equation 2 and Reckhow's procedure, phosphorus loadings to a lake and mean annual lake phosphorus concentrations can be estimated. Loadings are estimated based upon land use areas and phosphorus export coefficients. Phosphorus export coefficients for various land use types were carefully selected for use in the model from a compilation and comparison by Reckhow et al. (1980). Nonpoint sources included in the model were residential areas, agricultural lands, wetlands, forest and shrub land, lakeside septic systems, and the atmosphere. Export coefficients were selected for these sources according to climate, location, soil type and texture, human and traffic activities, and vegetative cover. No point sources of phosphorus were found in the watershed or included in the model.

For the sake of practicality, high, most likely, and low export coefficients were selected, allowing computation of high, most likely, and low phosphorus loadings and mean lake water column concentrations. The high and low estimates represent the computation's uncertainty, because actual phosphorus export coefficients were not measured in the Hudson Lake watershed. This uncertainty represents error that is in addition to Reckhow's empirical model error and must be included in the computation of total uncertainty. In other words, the range between the high and low estimates reflects the uncertainty inherent in extrapolating Reckhow's compilation of export coefficients to the study area.

Reckhow's phosphorus model predicts a mean annual water column average total phosphorus concentration of 0.06 mg/L. The 55% confidence limits bounding this estimate are 0.03 mg/L and 0.13 mg/L. Given the mean water column total phosphorus concentration of 0.18 mg/L measured in August 1988, and 0.06 mg/L measured in September 1990, the 0.06 mg/L estimate is not unreasonable. These field measurements are only indicative of two grab samples, not mean annual phosphorus concentrations.

Reckhow considers this level of phosphorus indicative of eutrophic lakes. Based upon this model, as well as the field water quality data, Hudson Lake must be classified as eutrophic, and lacking the some of the chemical and biotic characteristics desired by lake users. Admittedly, there are factors other than total phosphorus important in determining trophic status, such as sedimentation rate, aquatic macrophyte densities, and general primary productivity, some of which are discussed below.

Table 8 gives the phosphorus model's estimates of most likely phosphorus loadings to the lake by subbasin. Subbasin 1 is non-contributing and is omitted from the table and the phosphorus model. Reckhow's procedure computes nutrient loadings using the unit area loading method, where a nutrient export coefficient for a particular land use is multiplied by the area of that land use in the contributing watershed.

Table 8

NONPOINT SOURCE PHOSPHORUS LOADINGS (kg/yr) TO HUDSON LAKE

		Subbasin		
Source	**2**	**3**	**4**	**Total**
Residential	98	5	234	337
Forests	0	4	12	17
Agriculture	203	335	556	1,094
Wetlands	-19	-29	-18	-67
Septic Systems	0	0	78	78
Precipitation	0	0	52	52
Total	**282**	**316**	**914**	**1,512**

Agriculture and residential areas are the two leading sources of phosphorus to the lake, at about 72% and 22% of the total loading, respectively (Table 9 and Figure 6). The immediate drainage area of Hudson Lake, that is subbasin 4, is responsible for about 60% of the total loading. Subbasins 2 and 3 are each the source of about 20% of the lake's phosphorus loadings. Figure 3, the land use map, indicates that residential areas separate the agricultural fields from the lake. These residential areas also contain some palustrine wetlands that receive (and retain) runoff and pollutant loadings from the upslope agricultural areas. Hence the residential areas along the lakeshore may be more significant in the overall phosphorus budget of the lake than the Reckhow model indicates.

Lakeside septic systems are contributing about five percent of the lake's annual phosphorus loadings. The phosphorus budget estimate is moderately sensitive to soil retention of phosphorus from septic fields. If the soil retention coefficient in the model is set at zero, septic sources are still likely to be between 50 and 175 kg/yr, or, at most about nine percent of the total. Septic systems and their effects on the public's use of Hudson Lake are further discussed below.

Table 9

HUDSON LAKE PHOSPHORUS SOURCES

		Subbasin		
Source	**2**	**3**	**4**	**Total**
Residential	6%	0.4%	16%	22%
Forests	0%	0.3%	0.8%	1%
Agriculture	14%	22%	37%	72%
Wetlands	-1.3%	-1.9%	-1.2%	-4%
Septic Systems	0%	0%	5%	5%
Precipitation	0%	0%	3.5%	3%
Total	**19%**	**21%**	**60%**	**100%**

The estimates of the phosphorus model were used to place Hudson Lake on Vollenweider's phosphorus loading plot, Figure 7 (Vollenweider 1975). For comparison, some other lakes in northern Indiana, including some in LaPorte County, are also shown on Figure 7. The plot has three basic zones, and a lake's datum will fall within one of those zones: eutrophic, mesotrophic, or oligotrophic. The upper zone is eutrophic lakes; the bottom zone is oligotrophic lakes. Mesotrophy is indicated by a datum falling in the midregion of the plot. Hudson Lake clearly falls within the eutrophic zone.

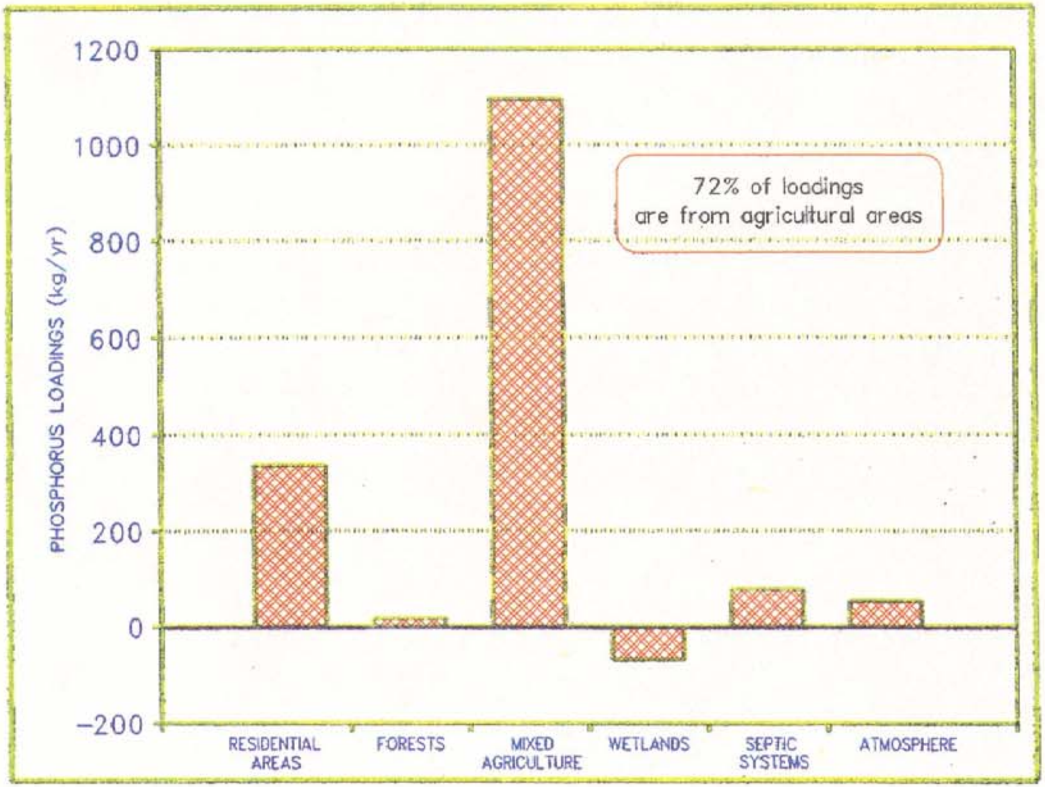
Sedimentation. Soil losses in the Hudson Lake watershed were estimated and routed downstream through Saugany Lake to Hudson Lake to evaluate mean annual sedimentation. Sediment particles can carry nutrients, pesticides, and other pollutants on their surfaces as they travel through a stream course. The magnitude of the sediment loading to Hudson Lake was evaluated as part of this study. Upland soil losses were estimated by applying the Universal Soil Loss Equation (USLE) to land under tillage in the watershed. Only a fraction of soil that is eroded actually leaves the watershed in the stream course, most is simply dislodged and deposited elsewhere in the watershed, like wetlands, lakes, and streambeds. This fraction is termed sediment production.

The USLE (Wischmeier 1976) computes upland soil loss as the product of six factors: area, a rainfall factor, a soil erodibility coefficient, a topography factor reflecting the degree and length of slope, a vegetative cover factor, and a conservation practice factor. These factors are based on actual precipitation and the properties of specific soil types and morphologies of the area. Values for these parameters used in this study were taken from Wischmeier and Smith, US Geological Survey Water Resources Data Reports for Indiana, and the LaPorte County Soil Survey. To simply the computations, tillage areas in each subbasin were broken down into two soil classifications used by the Soil Conservation Service: highly erodible lands and non-highly erodible lands. The parameters used in the USLE were weighted averages for each subbasin for each of these two lands.

The estimated soil losses from each subbasin were routed downstream by applying a sediment delivery ratio, taken from Figure 8 (Roehl 1962). The delivery ratio is a fraction of the sediment that actually is transported out of the subbasin as suspended sediment or bedload.

Another fraction of the eroded sediment is deposited or settles out as water travels through a water course, particularly in wetlands and lakes. The amount of deposition that occurs depends upon the amount of runoff and the volume of the lake or wetland. Trap efficiency factors have been applied to assess this deposition, based upon the lake or wetland volume. Trap efficiencies used in this study were taken from Figure 9. Trap efficiency for wetlands, which should behave similarly to dry reservoirs, was estimated using the approximate wetlands curve in Figure 9. The curve was derived from data for dry reservoirs (Roehl and Holeman 1973; USDA 1978), two semi-dry reservoirs (Brune 1988), and one wetland (Martin 1988). The curve was drawn parallel to the modified minimum Brune curve (Linsley et al. 1982) to split the data points and fall somewhat below the small-capacity/inflow ratio, wetland point.

Figure 6



HUDSON LAKE ENHANCEMENT FEASIBILITY STUDY

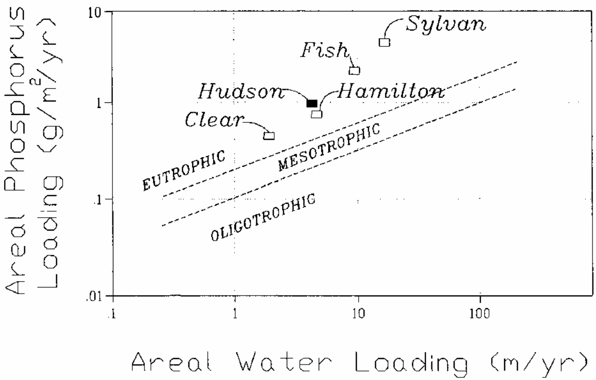
PHOSPHORUS LOADINGS TO HUDSON LAKE

HARZA ENGINEERING COMPANY, CHICAGO, ILLINOIS

APPROVED

DECEMBER, 1990

Figure 7



HUDSON LAKE ENHANCEMENT FEASIBILITY STUDY

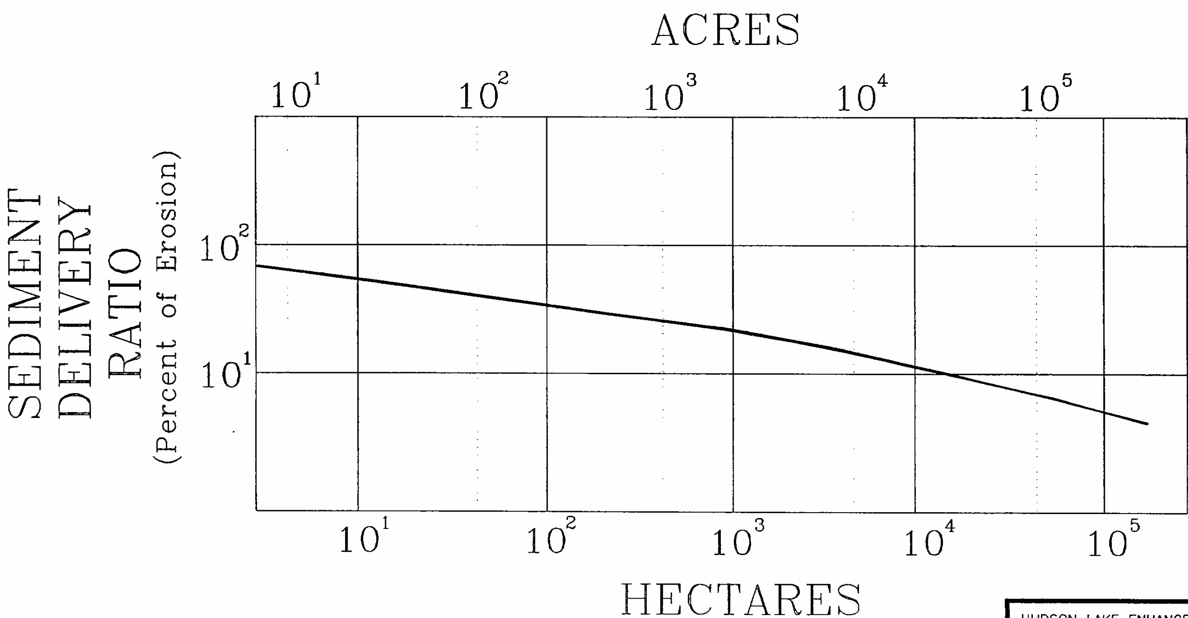
VOLLENWEIDER'S LOADING PLOT

HARZA ENGINEERING COMPANY CHICAGO, ILLINOIS

APPROVED

DECEMBER, 1990

Figure 8



HUDSON LAKE ENHANCEMENT FEASIBILITY STUDY

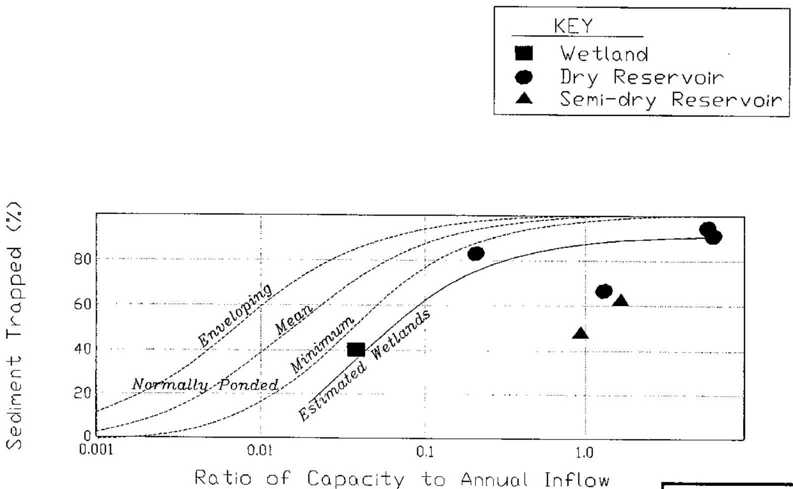
SEDIMENT DELIVERY RATIO VERSUS DRAINAGE AREA

HARZA ENGINEERING COMPANY, CHICAGO, ILLINOIS

APPROVED

DECEMBER, 1990

Figure 9



HUDSON LAKE ENHANCEMENT FEASIBILITY STUDY

RESERVOIR TRAPPING EFFICIENCY

HARZA ENGINEERING COMPANY, CHICAGO, ILLINOIS

APPROVED

DECEMBER, 1990

Results of the sedimentation computations are given in Appendix A-2 and are summarized below in Table 10. Three cases of sediment routing are given to document Harza's arrival at the most realistic routing, Case 3. Saugany and Hudson Lakes, because of their volume, will trap nearly all sediments passing through them. Saugany Lake traps about 98% of incoming sediment. Hence, with subbasin 1 being non-contributing, and Saugany Lake trapping 98% of the sediment from subbasin 2, sedimentation in Hudson Lake is largely from subbasins 3 and 4.

In subbasin 3, there is a large fen. Fens are alkaline wetlands and may trap significant amounts of sediment. Case 1 and Case 2 in Appendix A-2 contrast the sediment deposition that may be occurring in the fen. There are also "unconfirmed" reports that the marly fen was channelized. If there is no ponded water on the stream course, then the fen would not trap significant amounts of sediment (Case 1). With a storage volume equivalent to six inches of water covering the fen, it would have a trap efficiency of about 8%, and retain an annual average of about 145 tons of sediment. Hence the sediment budget to Hudson Lake is not sensitive to this distinction.

Table 10

SOIL LOSSES AND SEDIMENT PRODUCTION

	Row Crop Area (acres)	**Soil Loss (tons/yr)**	**Sediment Production (tons/yr)**
Subbasin 2	437	5,283	1,479
Subbasin 3	728	6,873	1,787
Subbasin 4	1,204	9,244	2,034

Saugany Lake receives about 1,480 tons per year in sediment. Figure 9 indicates that Saugany Lake should have a trapping efficiency of about 98%, so only about 30 tons of fine material are transported out of Saugany Lake during high flow events. Subbasin 3 adds about 1,790 tons of sediment each year to the 30 tons from Saugany Lake for transport downstream to subbasin 4. The marly fen probably traps less that about 8% of this.

Little Hudson Lake receives the input for subbasins 2 and 3, and about 20% of the subbasin 4 area. This 20% represents about 555 tons of sediment annually, which brings the annual average sediment loading to Little Hudson Lake to some 2,371 tons. Little Hudson Lake has a trapping efficiency of about 96%, so all but 95 tons is deposited in Little Hudson, the remainder passing into Hudson Lake proper. Hudson Lake receives this 95 tons of sediment plus that produced on the other 80% of subbasin

4, about 1,630 t/yr. Total loadings to Hudson Lake are therefore about 1,722 tons annually. Hudson Lake has a trapping efficiency of about 96%, so about 1,650 tons are deposited in the lake, and about 70 tons of finer material is transported downstream.

The soil loss rates computed for agricultural lands with the Hudson Lake watershed range between about 4 and 24 t/ac/yr. The tolerable limit "T" for soil loss in the study area is two to five t/ac/yr, depending on the soil unit. Therefore, soil losses are greater than "T" in the Hudson Lake watershed. Actual sediment production for the subbasins ranges between 1.7 and 3.4 t/ac/yr. Occurrence of wetlands and other features of the Hudson Lake watershed traps additional sediment before it reaches and impacts the lake.

Table 11 summarizes sediment trapping efficiency and average annual sediment deposition in Saugany Lake, Little Hudson Lake, and Hudson Lake. Assuming that deposition occurs equally over the entire lake surface, and that sediment density is about 85 lb/ft^3, a sedimentation rate can be estimated (Table 11). Although the assumption of equal deposition over the surface of the lake is unrealistic, these sedimentation rates are quite low for lakes in the agricultural upper Midwest.

Table 11

SEDIMENT LOADINGS, DEPOSITION, AND SEDIMENTATION RATES

Lake	Sediment Loadings (t/yr)	Trapping Efficiency (%)	Sediment Deposition (t/yr)	Sedimentation Rate (inches/yr)
Saugany	1,479	98	1,450	0.13
Little Hudson	2,371	96	2,276	0.13
Hudson	1,722	96	1,653	0.03

ISBH Surveys. On August 29, 1989, the Indiana State Board of Health performed a bacteriological survey of Hudson Lake. ISBH collected water samples along the lakeshore at various locations and tested *Escherichia coli* numbers. Copies of laboratory reports of this survey were made available to Harza by the LaPorte County Health Department. Table 12 summarizes the reports. These data indicate fecal contamination of Hudson Lake at several locations along the shore. Most of the tests were performed in the central area of the lake, just east of the island. The ISBH results indicate that as much as 25% of the septic systems are causing *Escherichia coli* concentrations in the lake to exceed the state water quality standard, particularly along the south shore of the lake. However, readers are cautioned against misinterpreting the Table 12 data, as only

14 samples were taken by ISBH. More extensive testing is recommended and, as warranted by these tests, remediation studies, designs, and construction mesures should follow.

The LaPorte County Health Department also availed Harza of IDEM letters to Hudson Lake homeowners. In July 1989, the IDEM collected well water samples and tested them for 70 chemicals and bacteriological quality. These letters reported that the water was of unsatisfactory bacteriological quality and considered unsafe for human consumption. Apparently five letters were sent out by IDEM, four of which contained the consumption advisory. All addresses were between 8197 North Emery Road and 7642 North Emery Road, in Rolling Prairie, IN.

Conclusion

Based upon the lake phosphorus model and the phosphorus testing results, Hudson Lake is eutrophic. According to the EI, Hudson Lake is a Class II lake, and warrants some protective and management actions, to prevent further deterioration of water quality and public use.

The residential areas along the lakeshore may be more significant contributors to the phosphorus budget of the lake than the Reckhow model indicates. These residential areas separate agricultural areas from the lake and contain some palustrine wetlands that retain runoff and pollutant loadings from the upslope residential and agricultural areas. The wetlands, and their role as nonpoint source pollution traps, should be preserved.

As soil losses in the watershed are greater than "T", upland BMP measures should be instituted for the areas producing sediment, that is, the areas under till. As seen in Appendix A USLE computations, subbasin 2 has the greatest soil losses from tilled land, and upland BMP implementation could have the greatest benefit there, particularly in terms of protecting Saugany Lake, a unique resource in the state. Subbasins 3 and 4 deliver significant sediment to Hudson Lake, and, BMP measures could have benefits on the more erodable land there. Little Hudson Lake traps much of the sediment entering during storms and its function as a sediment traps will continue for years to come.

There are indications that septic systems around the lake are poorly installed or have operational problems. This has serious health implications for body contact recreation in Hudson Lake and warrants further investigation, and potentially, remediation.

Table 12

RESULTS OF ISBH BACTERIOLOGICAL SURVEY

Address	Colonys /100mL	ISBH Comment
Clarks Twin Oaks	10	Collected 20' SW of shore
Clarks Twin Oaks	70	Between piers
7659 Lake Park Ave	600	Collected 2' offshore; suspected sewage contamination
7661 Lake Park Ave	580	Off pier, 15' out
7421 E. Point Rd	200	Suspected sewage discharge, 4' west of dock
7421 E. Point Rd	10	Collected 77' W of last sample
7423 E. Point Rd	<10	110' W of 5421 E; suspect sewage
E. Point Rd	900	20' W of 7423 E; at shoreline; suspect sewage contamination
7605 N. South Bend Blvd	10	approx 150 yds SW of 7605 N South Bend Blvd; 15' from shore, off west side of dock
7605 N. South Bend Blvd	10	approx 150 yds SW of 7605 N South Bend Blvd; 15' from shore, off west side of dock
7605 N. South Bend Blvd	160	1' N near sand pile
7605 N. South Bend Blvd	600	approx 50' E of last sample, at shoreline
SE shore 50 yds N of casino	60	2' off shore
SE shore 100 yds N of casino	40	2' off shore

EVALUATION OF LAKE ENHANCEMENT ALTERNATIVES

The purpose of an engineering feasibility study is to identify, compare, and screen project alternatives and to select one or more alternatives for further study, typically a design level study. In this chapter, alternatives for enhancing the lake are identified, and screened for applicability to Hudson Lake. Those alternatives that are appropriate, are evaluated for technical and environmental feasibility.

Hudson Lake is a valuable public resource. The public uses of the lake are being impacted by eutrophication and by septic contamination. The obvious symptom of eutrophication is the abundance of submersed and emergent aquatic vegetation. However, the casual user does not directly observe the high phosphorus and coliform bacteria concentrations.

Alternatives for enhancing Hudson Lake were evaluated using a classic three-level procedure, with the depth of study increasing as the list of alternatives narrowed to those most feasible. The evaluation system's three levels are:

Level 1.	**Initial Identification** - A comprehensive list of reasonable lake enhancement methods was compiled.
Level 2.	**General Screening** - Alternatives which were obviously not applicable to Hudson Lake, had unacceptable environmental impacts, or unproven technology were eliminated from further consideration.
Level 3.	**Feasibility Evaluation** - Alternative methods were evaluated for technical feasibility for enhancing Hudson Lake. Those alternatives remaining for evaluation at this level of study were prioritized for implementation based on effectiveness and cost.

Level One - Identification

A list of submersed macrophyte control alternatives is presented in Table 13. Table 14 is a list of alternatives for reducing phosphorus loadings to Hudson Lake. Beside each listed alternative are comments reflecting the applicability to the specific problem at Hudson Lake.

Best management practices (BMPs) for urban runoff control are listed in Table 15 and include source control practices (like increasing infiltration of storm water, retention of runoff, reduction of erosion, air pollution control, and street sweeping) and reduction of pollutant delivery to surface waters (changes in storm drainage systems, infiltration and sedimentation basins, flow equalization basins, and treatment of runoff). References on urban BMPs include Novotny and Chesters (1981), HHRCDC (1985), US EPA (1980) and SCS (1969). BMPs are very important for maintaining water quality. There are also policies that local governments can implement to improve and protect water quality in urban watersheds. Examples of such policies include the HERPICC model ordinance for erosion control and ordinances protecting wetlands.

Level Two - Screening

The initial list of alternatives was screened, and only those determined to be suitable for implementation were carried forward to the feasibility evaluation stage. The criteria for this screening included obvious applicability and utility, unacceptable environmental or social impacts, legal constraints, and unproven technology.

The macrophyte control alternatives carried on to the feasibility level of study were mechanical harvesting and herbicides. Only harvesting removes organic matter and nutrients from the lake. Water level fluctuations can control some types of macrophytes quite well. Hudson Lake's outlet is a fixed culvert and water level control is not possible using this outlet. Pumping or siphoning have been used on other lakes, and although this is technically feasible, direct adverse impacts would occur on the fish population, littoral wetlands, local water wells, and indirect adverse effects would occur to other environmental features such as waterfowl and aquatic mammals.

Three biological weed control mechanisms were identified; only one of these is developed sufficiently for temperate climates: weed-eating fishes. Insects and microorganisms are under study, but currently the technology is poorly developed for regions this far north. Triploid (genetically sterile) grass carp (Ctenopharyngodon idella) should be considered should this alternative ever be permitted in Indiana. However, they are illegal at present. Other alternatives not carried forward for feasibility evaluation, and the reasons for their elimination, are given in Table 13.

A detailed plant management plan should be prepared prior to implementation of a harvesting or an herbicide program. The objective of the plan would be to prioritize areas for public uses, and to specify the locations and degrees of macrophyte control to support these uses. Complete removal of aquatic plants is neither desirable nor possible. In a controlled removla of macrophytes, the nutrient pool may be controlled through plant growth and harvest. Occasionally, public uses are compatible with dense aquatic macrophyte stands, such as those activities dependant upon waterfowl or fish production. Boating, waterskiing, and swimming are in direct conflict with dense macrophyte colonies, however.

Table 13

ALTERNATIVES FOR CONTROLLING AQUATIC MACROPHYTES IN HUDSON LAKE

Method	Description	Suitability
Water Level Fluctuations	Exposes sediments to prolonged freezing and drying, killing roots and some species' seed. Submerges & kills some species.	Lake has no mechanism for significantly lowering water level; can have adverse effects on fisheries and wildlife.
Lake Shading	Dyes and water surface covers can shade and kill many plants.	Not suitable for large lake areas. Water surface covers, like black plastic, may be suitable for small, localized areas. Does not remove organic matter or nutrients from lake.
Phytophagous Fishes	Grass carp and other exotic plant-eating fishes can control some macrophytes.	Not legal in Indiana; can have adverse environmental impacts. Consider in the future if legalized.
Insects	Insects consume plants.	Technology poorly developed for northern climates.
Plant Pathogens	Microorganisms introduced to lake cause diseases in macrophytes.	Technology undeveloped.

Harvesting	Cutting and removing plants by mechanical means.	Requires repeated treatments; technology well developed; Hudson Lake has reasonably good access for off-loading weeds.
Herbicides	Use of selected chemicals to control plants.	Short-term effectiveness; technology well established. Does not remove organic matter or nutrients from lake.

Table 14

ALTERNATIVES FOR REDUCING PHOSPHORUS LOADINGS
TO HUDSON LAKE

Method	Description	Suitability
Hypolimnetic Withdrawal	Nutrient-rich hypolimnetic water discharged from the lake during stratification, resulting in a net annual loss of P from the system.	Lake does not display high hypolimnetic P concentrations; also, no mechanism currently exists at outlet for deep water withdrawal.
Nutrient Diversion	Diverting incoming P-rich waters to another basin or downstream of lake.	Inlets could be diverted to other lakes; will require significant rerouting of stream channel and have adverse environmental effects
Dilution or Flushing of Nutrients	Diluting lake with large volumes of nutrient-poor water.	No suitable water supply.
Lake Phosphorus Inactivation	Chemical binding of sediment phosphorus by Al salts.	Well tested; not effective in lakes with low internal phosphorus loadings.
Sediment Oxidation	Adding a reducing agent, like nitrate, to organic-rich sediment prevents hypolimnetic anoxia and sediment P release.	Effective, but not well tested, and must be repeated annually or biannually.

Table 14 (cont'd)

Sediment Removal	Dredging removes the source of internally loaded P and increases depth, reducing the likelihood of recurring weed problems.	High costs; not effective in lakes with low internal loading.
Hypolimnetic Aeration	Oxygenation of hypolimnion prevents sediment release of phosphorus.	Unsuitable since Hudson Lake does not have high internal loading.
Constructed wetlands	Functions as trap for particle-bound phosphorus, and as a biological treatment basin.	Effectiveness is design-dependant; maintenance required.
Artificial Circulation	Eliminates thermal stratification and aerates lake, using air bubbles or mechanical mixers.	Generally used to restore eutrophic lakes having plankton or metal (Fe, Mn) problems and high internal P loadings.

Table 15

NONPOINT POLLUTANT SOURCES AND CONTROL MEASURES FOR URBAN AREAS

Source	Control Measures
Street Surfaces	Street Cleaning Street Repair Alternative De-icing Methods Litter Control Pet Litter Control Cleaning Catch Basins Store and Treat Runoff
Parking Lots	Street Cleaning Leaf Removal Alternative De-icing Methods Use of Porous Pavement Store and Treat Runoff
Vacant Land	Control Grass Types Control Fertilizers & Pesticides Control Litter Regrade and Seed Distrubed Areas
Rooftops	Discharge Gutters to Lawns
Construction Sites	Clean Catch Basins Clean Storm Sewers and Drainage Channels Retain Runoff Regrade Disturbed Areas Direct Runoff Away from Contaminated Sites
Landscaped Areas	Leaf Removal Control Grass Types Control Fertilizer, Pesticides Control Dog Litter Store and Treat Runoff
Other (Industrial and Solids Waste Runoff)	Control Use of Vacant Land Control Direct Discharge to Storm Drains Eliminate Cross-Connections with Sanitary Sewers Direct Runoff Away from Contaminated Areas Store and Treat Runoff

Phosphorus control alternatives evaluated included both in-lake and watershed source control of phosphorus. In-lake phosphorus control basically involves restriction of sediment-generated or recycled phosphorus. In-lake phosphorus (also referred to as internal phosphorus) sources are generally significant in lakes that have accumulated large amounts of this nutrient in their sediments and are able, through summer anoxia, to recycle the phosphorus. Although Hudson Lake has accumulated phosphorus over the centuries, sampling during 1988 and 1990 summer anoxia did not indicate high hypolimnetic phosphorus or ammonia concentrations. Sediment feedback of nutrients does not seem to be significant in Hudson Lake. Assuming this is so, control of in-lake phosphorus by inactivation, aeration or other methods will not significantly affect the lake trophic status, and only watershed control methods are carried forward to the feasibility level of study.

Watershed control of phosphorus inputs to the lake is generally linked with control of nonpoint soil erosion and sedimentation through BMPs. Phosphorus is generally transported in streams adsorbed to soil particles, so removal of the soil particles from the stream system frequently removes incoming phosphorus as well. Watershed control of phosphorus and sediment loadings carried to the next level of study includes BMPs for residential or urban areas and wetland construction.

Level Three - Feasibility Evaluation

Harvesting. Harvesting, or cutting and removing aquatic plants, has been practiced in Midwestern lakes for many years. Although harvesting is especially effective at immediately improving lake uses, it has some lake restorative value because the plants are removed from the lake. Because they are removed, the plants do not decompose in the water, consume dissolved oxygen, and release their nutrients to the water column. Disposal of the weeds is not usually a problem. The vegetation makes excellent mulch and fertilizer for parks and gardens. Harvesters should cut the vegetation at least five feet deep. Harvesting, although easiest in water five to six feet deep, can be done in water that is deep enough to float the harvester (18 to 24 inches).

Macrophyte mowers are available but they do not remove the vegetation from the lake, and, although considerably less expensive than harvesters, mowers are not recommended.

Weed harvesters are available from specialty manufacturers. Alternatively, contract harvesting can be periodically performed. Contract harvesting costs will be between $35,000 and $65,000, depending on the harvested area (acres), biomass density, locations, and disposal site. Experience indicates that during the first year of harvesting, vegetation biomass removed from the lake is higher than in successive years, so costs may decrease over time.

Because there are several lakes in LaPorte County, and there are macrophyte problems on some of these lakes, the HLCC may be able to cooperate with other conservation groups, lake associations, or municipalities for implementation of a long-term harvesting program for substantially less than contracting for the harvesting. Table 16 itemizes the estimated costs for HLCC to implement its own harvesting program on the lake.

Table 16

MACROPHYTE HARVESTING PROGRAM

Purchase

Item	Amount
Aquamarine H5-200 Harvester	$41,000
Trailer/Conveyer	15,300
Delivery	400
	$56,700

Operation

Item	Amount
Labor (150 ac, 5 hr/ac @ $12/hr)	$9,000
Fuel (2 gal/hr @ $1.5/gal)	1,500
Maintenance (10%)	5,670
	$16,170

Adverse ecological effects are few. The weeds will return and harvesting will need to be repeated annually. Harvesting is generally increasingly effective in later years. With fewer macrophytes, phytoplankton concentrations may increase, and water clarity may decrease. Macrophytes should not be harvested from certain locations, such as the mouth of the inlet in Little Hudson Lake and other areas in that lake where rare aquatic plants are found. Recent research by the Tennessee Valley Authority indicates that large numbers of juvenile sunfish (*Lepomis* sp.) may be harvested with the aquatic plants.

Access to the lake front for offloading harvested weeds is excellent at Hudson Lake. The shoreline is paralleled by roads, and is unencumbered by private docks or piers. Disposal of the weeds should not be a problem either; the macrophytes make excellent compost, and can be used as a soil amendment.

Herbicides. Controlling macrophytes using herbicides is effective, but herbicide use is not lake restoration (i. e., does not remove nutrients). Some herbicides are specific to certain plants. Application needs to be done according to the manufacturer's instructions, and in Indiana, by licensed applicators. Herbicide use does not address the cause of weed growth, nor does it remove weed organic matter or nutrients from the lake. Herbicides do remove the hindrance to public use of the lake, however, by causing the plants to die. The dead plants decompose on the lake bottom, and eventually release their nutrients back to the water column. Plankton blooms may occur in lakes after major herbicide applications; this is linked to the release of nitrogen and phosphorus from the decaying plants. Hudson Lake, because of its relatively long hydraulic retention time, would likely experience these blooms after herbicide applications, depending of course on the amount of vegetation killed.

The major problem macrophytes in Hudson Lake are watermilfoil, coontail, and curlyleaf pondweed, and, the alga chara. The herbicide generally recommended for control of coontail and watermilfoil is the granular ester, or liquid forms, of 2,4-D (2,4-dichlorophenoxy acetic acid) to create an in-lake concentration of about two parts per million. 2,4-D is somewhat specific to exotic species among submersed plants at this concentration, but is quite toxic to many native emergents, those plants that HLCC should conserve because of their value to wildlife. Algae control can be done well using copper-based algicides. At Hudson Lake, because of the hardness of lakes in this region, only the chelated forms of copper are recommended. Application should be by a licensed commercial applicator (lists of which are available from Harza or the DNR).

Materials for herbicidal macrophyte and algae control will cost about $12,300: $6,300 for 2,4-D and $6,000 for chelated copper. Labor for application is estimated at $1,200, for a total cost estimate of about $13,500.

Best Management Practices. The US EPA, SCS, and other agencies have developed BMPs for watershed management and lake water quality protection. Many BMPs focus on runoff control, but have coincidental water quality benefits. An example control method for agricultural lands that is already in place is the Conservation Reserve Program (CRP), where highly erodible lands are taken out of production and set aside for ten years. Nutrient and sediment input to downstream lakes will probably be reduced because of the CRP set-aside lands in the basin. A second possibility is enrolling of eligible lands in a sister provision to the Conservation Reserve, the Conservation Compliance Program which maintains land in production but requires farm management plans for control of soil erosion. Such a management plan might recommend that conventionally tilled highly erodible lands be placed in contour terraces and tilled by chisel plow.

Besides programs to control erosion, nutrient management programs may be able to encourage more efficient and profitable use of fertilizers. By reducing application of excess fertilizer, a nutrient management program may reduce nitrogen and phosphorus loadings to wetlands (and the lake) and prolong their effectiveness as sinks for these nutrients.

Agricultural BMPs are most cost effective when they target relatively small areas of highly erodible lands where CRP enrollment or installation of other conservation practices can significantly reduce sediment yield. The HLCC is encouraged to solicit the assistance of the SCS District Conservationist and the "T by 2000" office for further technical and economic studies of the potential for upland BMPs to enhance Hudson Lake.

At Hudson Lake, the agricultural areas are separated from the lake by large residential lands and scattered wetlands. As mentioned previously, the wetlands likely detain flood waters, sediments, and nutrients from the upslope agricultural areas and help protect the lake. The residential areas, because of their closer proximity to the lake, may deserve higher priority for BMP implementation than the agricultural areas.

Several of the measures listed in Table 15 can be applied to these areas, and, again, most are aimed at controlling storm water runoff and have incidental water quality benefits. Of the BMPs listed in Table 15, the sources that can be most effectively controlled in the study area are construction sites and landscaped areas.

BMPs for lakeshore construction (e.g. sea walls and docks) are generally included in permit conditions, so by HLCC increasing public awareness for the required construction permits, developers will be legally bound to BMPs. However, construction activities away from the lake may not be subject to state or federal permits and can have serious impacts to downstream water quality if erosion control is not practiced at the site. Again, public awareness is key to implementing BMPs in such situations, by passing and enforcing local erosion control ordinances.

Landscaped areas, such as private yards or public parks, can contribute pollutant loadings to lakes by the fertilization practices there, the runoff of pet wastes, or leaf litter contamination of the lake. Through public awareness, HLCC can educate homeowners about these practices. Homeowners can be asked to observe the direction and rate of runoff from their property during rainstorms and, as appropriate, redirect runoff to one of the many wetlands around the lake, or slow runoff by altering vegetative cover on their land.

The "T by 2000" office has a public education program and the HLCC is encouraged to contact them for assistance in developing a BMP program. HERPICC (1989) is a model ordinance for erosion control on sites with land disturbing activities, and could be a starting point for a local BMP initiative. Also, the Hoosier Heartland Resource Conservation and Development Council (1985) offers a planning guide for urban development (erosion control, sediment control, flood prevention, and drainage).

Constructed Wetlands. Much research has been done in the last decade concerning the benefits of wetlands to downstream water quality (Hammer 1989). To offer effective water quality restoration, wetlands are somewhat land intensive, requiring about 20 acres for every cubic foot per second of average annual hydraulic loading. The area of land required for effective constructed wetlands is not available in the vicinity where it is required, i.e. the residential areas; and if it were, purchase of that land would be rather costly.

HLCC, however, can conserve the wetlands in its watershed by making the public aware of their value to the lake and by petitioning local regulatory agencies to enforce wetland conservation laws. The HLCC can also cooperate with the owner of the marly fen west of the lake to inspect and determine the fen's flood detention capability, and, if it has been channelized, restore it. Natural resource management agencies (DNR Division of Fish and Wildlife, US Fish and Wildlife Service) or qualified consultants should be requested for assistance in this restoration process.

Recommendations for Implementation.

If the HLCC desires to control the aquatic plants in Hudson Lake, we recommend that a detailed macrophyte management plan be prepared to identify the public's interest in controlling plants, and to locate areas and determine the degree of control desires to support these public interests. In general, harvesting is recommended over the use of aquatic herbicides for controlling plants because of harvesting's restorative value to lake water quality. Herbicides, however, because of their lower costs to implement, may be more economically feasible (economic analyses were not performed).

Best management practices for Hudson Lake should be written into local ordinances. The "T by 2000" Program includes technical assistance for non-agricultural erosion control. Services under this program include providing detailed soil mapping and interpretations on lands being considered for intense or specialized use, making on-site evaluations to identify and characterize potential erosion problems, to assist in solving these problems, and presenting programs to interested groups on urban watershed management.

Table 17

SUMMARY OF RECOMMENDATIONS

Recommendation	Costs	Comments
Aquatic Plant Harvesting	$35,000 for contractor less for self-harvesting	Recommended over herbicides for plant control, economics not withstanding. Aquatic plant management plan recommended.
Herbicidal Plant Control	$13,500	Recommended for cost reasons only. Aquatic plant management plan recommended.
Land Best Management Practices	Not estimated	Residential BMPs recommended. Seek further assistance from "T by 2000" office
Constructed Wetlands	Not estimated	Insufficient land for constructed wetlands. Conservation and restoration of existing wetlands encouraged. Seek further assistance from "T by 2000" office

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LAKE PHOSPHORUS MODEL

$P = L/(11.6 + 1.2 * qs)$

Where: P = Lake phosphorus concentration (mg/L)

L = Phosphorus loading (g/sq m-yr)

qs = Areal water loading (m/yr)

Estimation of qs for Hudson Lake:

$Q = (Ad * r) + (Ao * Pr)$

and

$qs = Q/Ao$

Where: Q = Inflow water volume (cu m/yr)

Ao = Lake surface area =	1,748,304	sq m
Ad = Contributing watershed area =	14,078,349	sq m
r = Total annual unit runoff =	0.296	m/yr
Pr = Mean annual net precipitation =	0.901	m/yr

Q = 5.74E+06 cu m/yr

qs = 3.29 m/yr

Estimation of L for Hudson Lake

$M = (Er * Ar) + (Ef * Af) + (Ea * Aa) + (Ew * Aw) + (Ep * Ao) + (Es * C * (1-Ks))$

and

$L = M / Ao$

Where: M = Total phosphorus mass loading (kg/yr)

Er = P export coefficient for residential land (kg/ha-yr)

Ar = Area of residential land (ha)

Ef = P export coefficient for forest land (kg/ha-yr)

Af = Area of forest land (ha)

Ea = P export coefficient for agricultural land (kg/ha-yr)

Aa = Area of agricultural land (ha)

Ew = P export coefficient for wetland (kg/ha-yr)

Aw = Area of wetland (ha)

Ep = P export coefficient for precipitation (kg/ha-yr)

Es = P export coefficient for septics (kg/C-yr)

C = number capita-years serviced by septics

Ks = Soil retention coefficient

Sources	Area		Phosphorus Export Coefficients High	Most Likely	Low	
Residents	337	ha	2.5	1.0	0.4	kg/ha-yr
Forest	149	ha	0.3	0.15	0.05	kg/ha-yr
Agriculture	1,345	ha	4.0	1.0	0.5	kg/ha-yr
Wetland	202	ha	0.02	-0.4	-1	kg/ha-yr
Septics	174	cap-yrs	1	0.6	0.3	kg/cap-yr
Precip	175	ha	0.6	0.3	0.2	
	2,381	ha				

Basin 1	Phosphorus Mass Loading High	Most Likely	Low	
Resident	0	0	0	kg/yr
Forests	11	6	2	
Ag land	1,004	251	126	
Wetland	1	-14	-35	
M =	1,016	243	92	kg/yr

0% loadings transported out of subbasin

Basin 2	Phosphorus Mass Loading High	Most Likely	Low	
Resident	245	98	39	kg/yr
Forests	0	0	0	
Ag land	814	203	102	
Wetland	1	-19	-48	
M =	1,059	282	92	kg/yr

100% loadings transported out of subbasin

Basin 3	Phosphorus Mass Loading			
	High	Most Likely	Low	
Resident	13	5	2	kg/yr
Forests	9	4	1	
Ag land	1,339	335	167	
Wetland	1	-29	-72	
M =	1,363	316	99	kg/yr

100% loadings transported out of subbasin

Basin 4	Phosphorus Mass Loading			
	High	Most Likely	Low	
Resident	585	234	94	kg/yr
Forests	25	12	4	
Ag land	2,223	556	278	
Wetland	1	-18	-46	
Septics	130	78	26	
Precip	105	52	35	
M =	2,833	784	330	kg/yr

Total	Phosphorus Mass Loading			
	High	Most Likely	Low	
Resident	843	337	135	kg/yr
Forests	34	17	6	
Ag land	4,375	1,094	547	
Wetland	3	-67	-167	
Septics	130	78	26	
Precip	105	52	35	
M =	5,490	1,512	582	kg/yr

Areal Phosphorus Loading (L):

High =	3.1	g/sq m/yr
Most likely =	0.9	
Low =	0.33	

Lake Phosphorus Concentration (P):

High =	0.202	mg/L
Most likely =	0.056	
Low =	0.021	

ESTIMATION OF UNCERTAINTY (St)

log P (most likely) =	-1.255	
"Positive" model error =	0.0191	mg/L
"Negative" model error =	-0.0142	mg/L
"Positive" loading error =	0.0732	mg/L
"Negative" loading error =	0.0171	mg/L
"Positive" uncertainty =	0.0756	mg/L
"Negative" uncertainty =	0.0222	mg/L
55% confidence limits (lower) =	0.033	mg/L
55% confidence limits (upper) =	0.131	mg/L
90% confidence limits (lower) =	0.0112	mg/L
90% confidence limits (upper) =	0.207	mg/L

Lake Hudson Land Useage
Row Crop Soils Breakdown for Highly Erodible Soils (HES)

Subbasin	Section	Total Row Crop Acreage	HES (acres)	Type of Soil and Breakdown (acres)								USLE Constant Values (where more than one type of soil is present, a weighted average was used)					Soil Loss (Tons/Yr)
				ChC	MrB2	RLC2	RLD2	RLF	TcC2	TcD2	TcF	R	K	LS	C	P	
(1)	25	37	11	--	--	--	--	--	11	--	--	160	0.24	1.664	0.30	1	211
(non-	26	109	18	--	--	--	--	--	18	--	--	160	0.24	1.664	0.30	1	345
contributing)	35	312	95	--	--	--	--	--	73	22	--	160	0.24	1.913	0.30	1	2094
	36	100	37	--	--	--	--	--	36	1	--	160	0.24	1.693	0.30	1	722
	Subtotals	558	161	0	0	0	0	0	138	23	0						3371
2	19	33	7	--	--	7	--	--	--	--	--	160	0.32	1.342	0.30	1	144
	24	152	62	--	--	55	7	--	--	--	--	160	0.32	1.511	0.30	1	1439
	25	193	64	--	--	14	--	--	22	28	--	160	0.26	2.068	0.30	1	1652
	26	47	2	--	--	--	--	--	2	--	--	160	0.24	1.664	0.30	1	38
	30	12	8	--	--	3	3	--	--	2	--	160	0.31	2.041	0.30	1	243
	Subtotals	437	143	0	0	79	10	0	24	30	0						3372
3	19	226	24	--	--	24	--	--	--	--	--	160	0.32	1.342	0.30	1	495
	25	50	33	--	--	--	--	--	29	--	4	160	0.24	2.64	0.30	1	1004
	30	250	64	--	--	24	2	--	12	24	2	160	0.27	2.321	0.30	1	1925
	31	90	10	--	--	--	--	--	10	--	--	160	0.24	1.664	0.30	1	192
	36	112	10	--	--	--	--	--	10	--	--	160	0.24	1.664	0.30	1	192
	Subtotals	728	141	0	0	48	2	0	61	24	6						3312
4	19	71	24	--	--	24	--	--	--	--	--	160	0.32	1.342	0.30	1	495
	20	260	100	--	--	66	31	3	--	--	--	160	0.32	2.082	0.30	1	3198
	21	155	117	--	34	26	45	12	--	--	--	160	0.35	2.593	0.30	1	5097
	28	7	0	--	--	--	--	--	--	--	--	0	0	0	0	0	0
	29	71	25	--	--	--	--	--	22	3	--	160	0.24	1.798	0.30	1	518
	30	73	40	--	--	2	--	--	27	9	2	160	0.24	2.353	0.30	1	1084
	31	229	107	--	--	--	--	--	65	42	--	160	0.24	2.086	0.30	1	2571
	32	318	104	4	--	--	--	--	63	37	--	160	0.25	2.19	0.30	1	2733
	33	20	3	--	--	--	--	--	--	3	--	160	0.24	2.74	0.30	1	95
	Subtotals	1204	520	4	34	118	76	15	177	94	2						6483
Totals (exclude Subbasin 1)		2369	804	4	34	245	88	15	262	148	8						13168

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Lake Hudson Land Use
Row Crop Soils Breakdown for Non-Highly Erodible Soils (Non-HES)

Subbasin	Section	Total Row Crop Acreage	Non-HES (acres)	Type of Soil and Breakdown (acres)																	USLE Constant Values (where more than one type of soil is present, a weighted average was used)					Soil Loss (Tons/Yr)
				BaA	CoA	CoB	HaA	Hh	Hk	Hm	Pe	Ph	Qu	RLA	RLB2	TcA	TcB	Tr	Ua (Ud)	Wh	R	K	LS	C	P	
(1)	25	37	26	--	--	--	--	--	--	--	--	--	--	--	19	--	3	--	--	4	160	0.32	0.462	0.30	1	184
(non-contributing)	26	109	91	5	--	--	--	--	--	--	8	--	--	20	10	10	30	--	--	8	160	0.29	0.379	0.30	1	483
	35	312	217	--	--	--	--	19	--	--	--	--	--	--	10	8	170	10	--	--	160	0.23	0.629	0.30	1	1476
	36	100	63	--	--	--	--	--	--	--	--	--	4	--	5	21	30	--	--	3	160	0.26	0.452	0.30	1	353
	Subtotals	558	397	5	0	0	0	19	0	0	8	0	4	20	44	39	233	10	0	15						2495
2	19	33	26	11	--	--	--	7	--	--	--	--	--	--	8	--	--	--	--	--	160	0.28	0.293	0.30	1	103
	24	152	90	29	--	--	--	9	--	--	2	--	--	--	50	--	--	--	--	--	160	0.32	0.358	0.30	1	500
	25	193	129	--	--	--	14	--	--	--	--	--	--	2	14	24	66	3	5	1	160	0.24	0.766	0.30	1	1152
	26	47	45	--	12	--	--	--	--	--	--	--	--	11	9	--	10	3	--	--	160	0.30	0.352	0.30	1	228
	30	12	4	--	--	--	--	--	--	--	--	--	--	--	4	--	--	--	--	--	160	0.32	0.493	0.30	1	30
	Subtotals	437	294	40	12	0	14	16	0	0	2	0	0	13	85	24	76	6	5	1						1911
3	19	226	202	92	--	--	6	4	--	14	2	--	--	26	52	--	--	--	--	6	160	0.34	0.253	0.30	1	837
	25	50	17	--	--	--	--	--	--	--	--	--	--	--	--	--	17	--	--	--	160	0.24	0.730	0.30	1	143
	30	250	186	--	--	10	--	--	6	12	--	--	--	26	49	--	71	--	8	4	160	0.26	0.797	0.30	1	1842
	31	90	80	--	--	2	--	--	--	--	--	--	--	--	--	--	78	--	--	--	160	0.24	0.730	0.30	1	678
	36	112	102	--	--	14	--	--	--	--	--	--	--	--	--	--	88	--	--	--	160	0.25	0.730	0.30	1	897
	Subtotals	728	587	92	0	26	6	4	6	26	2	0	0	52	101	0	254	0	8	10						3561
4	19	71	47	5	--	--	--	2	--	11	--	--	--	--	27	--	--	--	--	2	160	0.25	0.346	0.30	1	194
	20	260	160	54	--	--	--	8	--	11	3	--	--	--	74	--	6	--	--	4	160	0.32	0.341	0.30	1	832
	21	155	38	5	--	--	--	8	--	2	--	--	--	6	13	--	--	--	--	4	160	0.26	0.289	0.30	1	136
	28	7	7	--	4	--	--	--	--	--	--	--	--	--	1	--	1	--	--	1	160	0.32	0.278	0.30	1	29
	29	71	46	--	--	--	--	3	--	--	--	--	--	--	--	--	43	--	--	--	160	0.23	0.698	0.30	1	347
	30	73	33	--	--	--	--	4	--	4	--	--	--	--	2	--	23	--	--	--	160	0.19	0.584	0.30	1	175
	31	229	122	--	--	--	--	--	--	--	--	4	--	--	--	--	99	15	--	4	160	0.25	0.620	0.30	1	914
	32	318	214	--	--	--	--	--	--	--	--	--	--	--	--	21	185	3	--	4	160	0.24	0.650	0.30	1	1616
	33	20	17	--	--	--	--	--	--	--	--	--	--	--	--	13	4	--	--	--	160	0.24	0.288	0.30	1	56
	Subtotals	1204	684	64	4	0	0	25	0	28	3	4	0	6	117	34	361	18	0	19						2761
Totals (exclude Subbasin 1)		2369	1565	196	16	26	20	45	6	54	7	4	0	71	303	58	691	24	13	30						8232

HARZA Engineering Company - January, 1991

Hudson Lake Sediment Routing

Case 1 (See Note)

Subbasin/ Lake or Wetland (1)	Row Crop Area (2)	Total Soil Loss (USLE) (3)		Sediment Delivery Ratio (4)	Total Transported From Subbasin (5)		Total Trans from Subbasin plus Upstream Subbasin (6)	Trap Efficiency Ratio (7)	Total Deposited in Lake or Wetland (8)	Total Transported to Downstream Subbasin (9)
	(Acres)	(Tons/Yr)	(Tons/Ac/Yr)		(Tons/Yr)	(Tons/Ac/Yr)	(Tons/Yr)		(Tons/Yr)	(Tons/Yr)
Subbasin 2	437	5283	12.1	28%	1479	3.4	-	-	-	-
Saugany Lake	-	-	-	-	-	-	1479	98%	1450	30
Subbasin 3	728	6873	9.4	26%	1787	2.5	-	-	-	-
(Wetland)	-	-	-	-	-	-	1817	-	-	1817
Subbasin 4	1204	9244	7.7	22%	2034	1.7	-	-	-	-
Hudson Lake	-	-	-	-	-	-	3850	96%	3696	154
Totals	2369	21400	9.0		5300	2.2			3696 (Lake Hudson)	154

NOTE: The following routing was used: Subbasin 1 was excluded. Subbasin 2, with Saugany Lake, was included. Subbasin 3 was included and it was assumed that the wetlands were channeled and therefore did not trap sediments.
Subbasin 4 was included with Little Hudson Lake and Hudson lake considered to be one lake.

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Hudson Lake Sediment Routing

Case 2 (See Note)

Subbasin/ Lake or Wetland (1)	Row Crop Area (2)	Total Soil Loss (USLE) (3)		Sediment Delivery Ratio (4)	Total Transported From Subbasin (5)		Total Trans from Subbasin plus Upstream Subbasin (6)	Trap Efficiency Ratio (7)	Total Deposited in Lake or Wetland (8)	Total Transported to Downstream Subbasin (9)
	(Acres)	(Tons/Yr)	(Tons/Ac/Yr)		(Tons/Yr)	(Tons/Ac/Yr)	(Tons/Yr)		(Tons/Yr)	(Tons/Yr)
Subbasin 2	437	5283	12.1	28%	1479	3.4	-	-	-	-
Saugany Lake	-	-	-	-	-	-	1479	98%	1450	30
Subbasin 3	728	6873	9.4	26%	1787	2.5	-	-	-	-
(Wetland)	-	-	-	-	-	-	1817	8%	145	1671
Subbasin 4	1204	9244	7.7	22%	2034	1.7	-	-	-	-
Hudson Lake	-	-	-	-	-	-	3705	96%	3557	148
Totals	2369	21400	9.0		5300	2.2			3557 (Hudson Lake)	148

NOTE: The following routing was used: Subbasin 1 was excluded. Subbasin 2, with Saugany Lake, was included. Subbasin 3 was included and it was assumed that the wetlands were not channeled and contained water at a depth of six inches. Subbasin 4 was included with Little Hudson Lake and Hudson lake considered to be one lake.

Hudson Lake Sediment Routing

Case 3 (See Note)

Subbasin/ Lake or Wetland (1)	Row Crop Area (2)	Total Soil Loss (USLE) (3)		Sediment Delivery Ratio (4)	Total Transported From Subbasin (5)		Total Trans from Subbasin plus Upstream Subbasin (6)	Trap Efficiency Ratio (7)	Total Deposited in Lake or Wetland (8)	Total Transported to Downstream Subbasin (9)
	(Acres)	(Tons/Yr)	(Tons/Ac/Yr)		(Tons/Yr)	(Tons/Ac/Yr)	(Tons/Yr)		(Tons/Yr)	(Tons/Yr)
Subbasin 2	437	5283	12.1	28%	1479	3.4	-	-	-	-
Saugany Lake	-	-	-	-	-	-	1479	98%	1450	30
Subbasin 3	728	6873	9.4	26%	1787	2.5	-	-	-	-
(Wetland)	-	-	-	-	-	-	1817	-	-	1817
Subbasin 4 (20%)	241	1849	7.7	30%	555	2.3	-	-	-	-
Little Hudson Lake	-	-	-	-	-	-	2371	96%	2276	95
Subbasin 4 (80%)	963	7395	7.7	22%	1627	1.7	-	-	-	-
Remainder of Hudson Lake	-	-	-	-	-	-	1722	96%	1653	69
Totals	2369	21400	9.0		5448	2.3			3929 (Hudson Lake)	69

NOTE: The following routing was used: Subbasin 1 was excluded. Subbasin 2, with Saugany Lake, was included. Subbasin 3 was included and it was assumed that the wetlands were channeled and therefore did not trap sediments. Subbasin 4 was divided approximatley into basins contributing to Little Hudson Lake and the remainder of Hudson Lake, sediment was routed through Little Hudson Lake into the reaminder of Hudson Lake.

Appendix B
GLOSSARY OF TECHNICAL TERMS

Anoxia	A condition of no oxygen in the water. Often occurs near the bottom of fertile stratified lakes in the summer and under ice in late winter.
Alkalinity	The buffering capacity of water.
Coliform bacteria	A group of microorganisms that is the principal indicator of the suitability of water for domestic or other uses and the sanitary quality of that water.
Epilimnion	Uppermost, warmest, layer of a lake during summertime thermal stratification. The epilimnion extends from the surface to the thermocline.
Eutrophic	Waters with a good supply of nutrients and hence high organic production.
Eutrophication	The process of lake aging, involving physical, chemical, and biological changes associated with nutrient, organic matter, and silt enrichment of a lake. If the process is accelerated by man-made influences, it is termed cultural eutrophication.
Hypolimnion	Lower, cooler layer of a lake during summertime thermal stratification.
Kjeldahl nitrogen	Organic nitrogen plus ammonia nitrogen.
Macrophytes	Rooted and floating aquatic plants, commonly referred to as waterweeds.
Mesotrophic	Waters moderately rich in plant nutrients.
Non-point source pollution	Pollutants that do not originate from a pipe or single source.
Oligotrophic	Waters with a small supply of nutrients and low organic productivity.
Orthophosphorus	A simple form of phosphorus that is readily available for uptake by plants.

Phytoplankton	Microscopic algae that float freely in open waters.
Fecal streptococci	A group of organisms indicative of fecal pollution from warm blooded animals.
Thermocline	A horizontal plane across a lake at the depth of the most rapid vertical change in temperature and density in a stratified lake; the transition zone between the epilimnion and the hypolimnion.
Wetland	Areas that are inundated or saturated by surface or ground water, with vegetation adapted to living in saturated soil conditions. Generally includes swamps, marshes, bogs, and similar areas.